3-24-2021

WCU's Geoexchange System, Stream Salinization, and Heated Sidewalks: Exercises in Sustainable Connections

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Martin Helmke, Patricia Haug, and Abigail Keebler

Department of Earth and Space Sciences

March 24, 2021

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WCGI
West Chester Geoscience Institute

Project Support

WCU Facilities and Grounds: John Lattanze, Timothy Smith, Dustin Zappone, Joshua Braid, Greg Cuprak, Bruce Wilson

Faculty Collaborators: Dr. Ulrich Klabunde, Dr. Tim Lutz

Stroud Water Research Center: Dr. John Jackson, David Bressler, Shannon Hicks, and others

Engineering Design: Neal Babcock and Howard Alderson

Graduate Students: David Kodokian, Denise Gatlin, Jacky Wilson

Undergraduate Students: Angela Reed, Jacob Thompson, and Kirsten Moore

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Dr. Sandra Mather

US Department of Energy Geothermal Technologies Program

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PA Department of Community and Economic Development

WCU Office of Sponsored Research

WCU College of the Sciences and Mathematics

WCU Foundation

WCU Student Technology Fee

Talk Outline

- Sustainability of the Geothermal System on the WCU Campus (Helmke)
- Salinization of West Chester Streams from Deicing Salt (Haug)
- Drones and Heated Sidewalks for Thermal Sustainability and Deicing Alternative (Keebler)

Hydrogeothermal Electricity Production

•Utilize near-surface geothermal features to supply steam to drive turbines

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Hydrogeothermal Electricity Production

- 10.7 GW electricity worldwide; 3.1 GW in US
- Maximum potential between 35 and 2,000 GW

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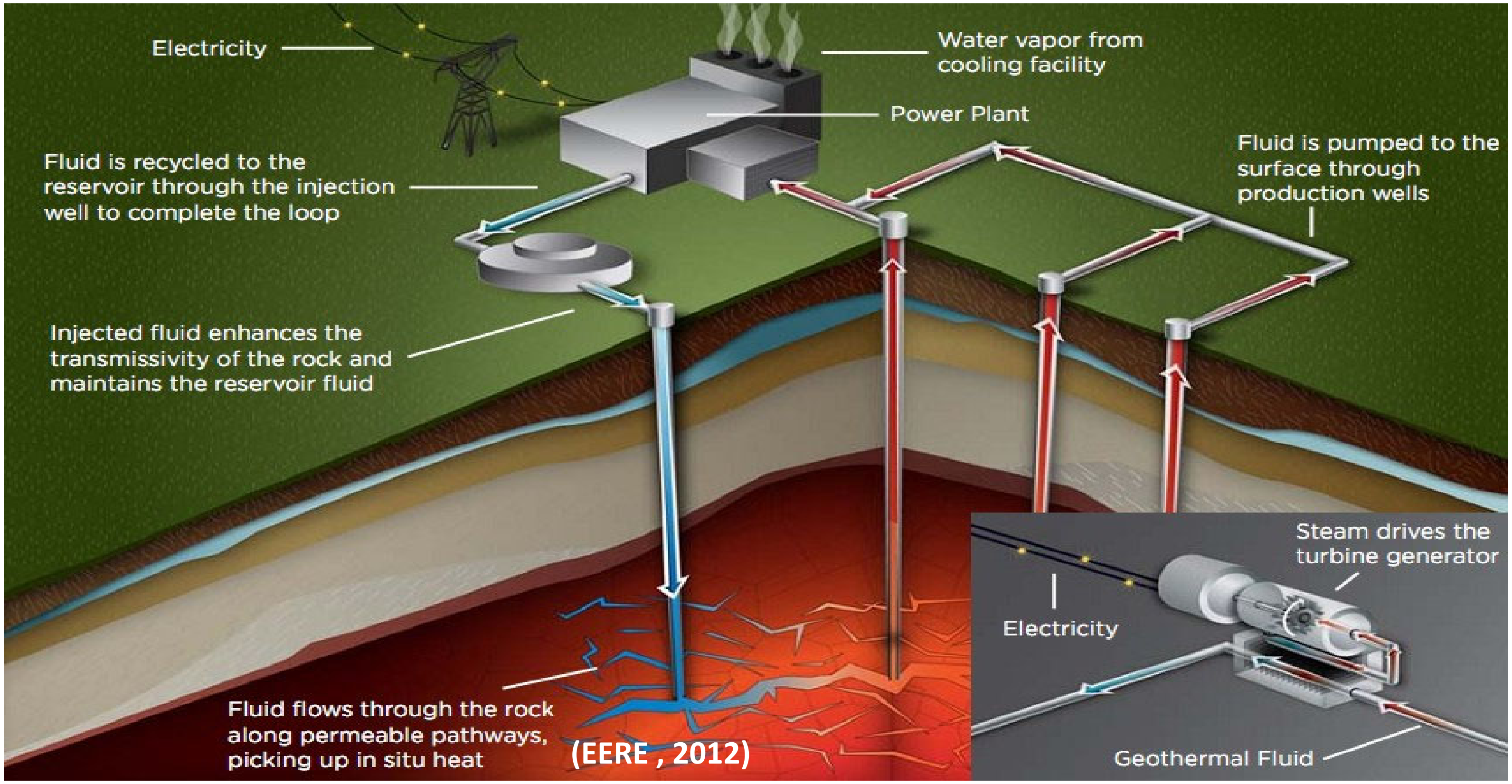
Enhanced Geothermal Systems (EGS)

- Deep (3-10 km) wells inject water into hot rock for steam
- 100 GW in US potential by 2050 (US electric cap. 1,051 GW)
- 200 ZJ extractable in the US (Tester et al., 2006)



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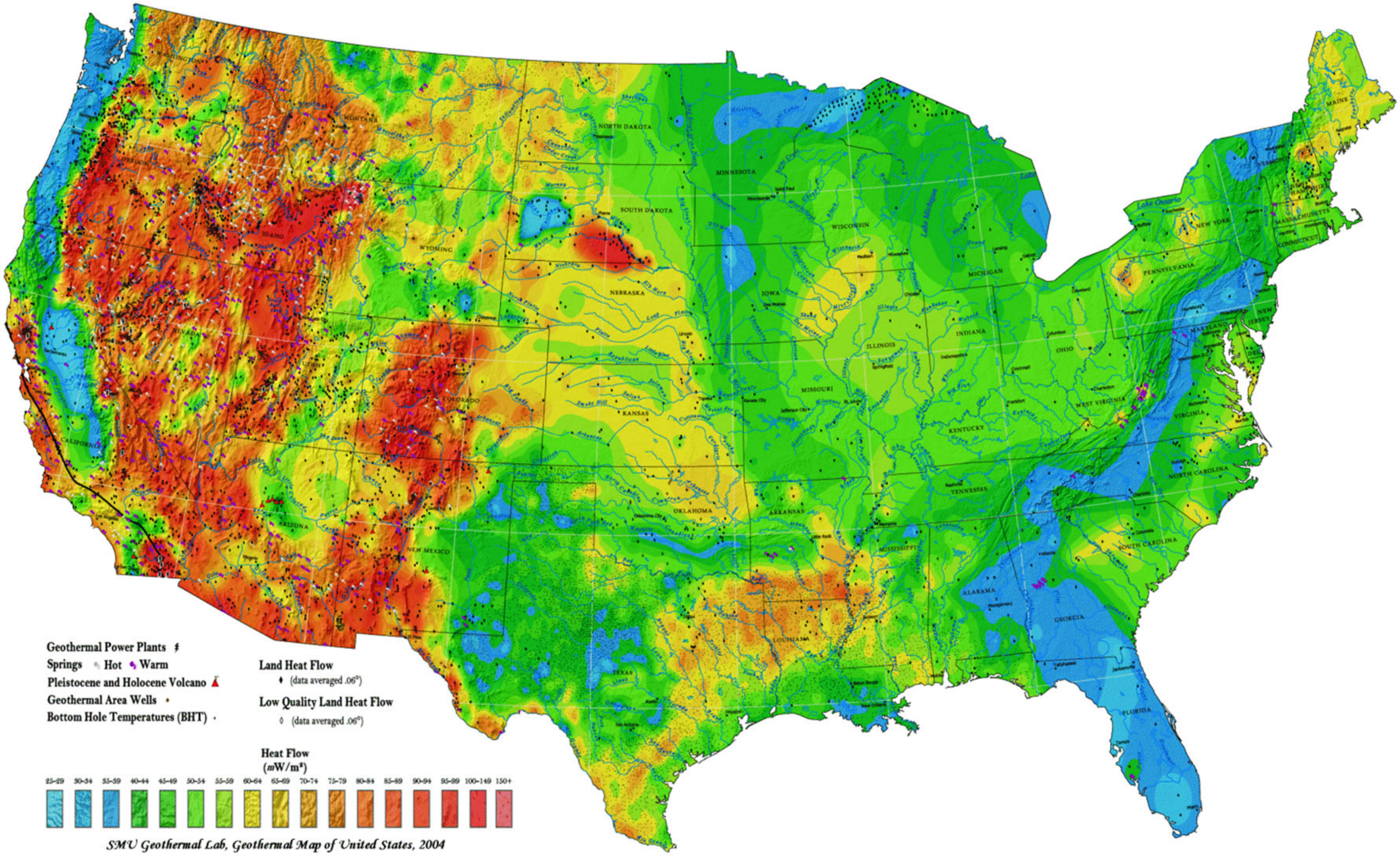
Geothermal Heat Flux



Blackwell, D. D., and Richards, M. 2004

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Ground-Source Heat Pumps
aka GeoExchange or “Geothermal” Systems

- Near-surface earth used as a heat source/sink
- Over 1M systems in the U.S.; 12 GW thermal capacity
- 3M systems worldwide; 35 GW capacity
- A typical household geothermal system saves $1,000/yr
- Typical household system costs $25k
- Payoff in 4-8 years with subsidies

Vertical Closed-Loop

Horizontal Closed-Loop

Open-Loop

(Bony, 2012)

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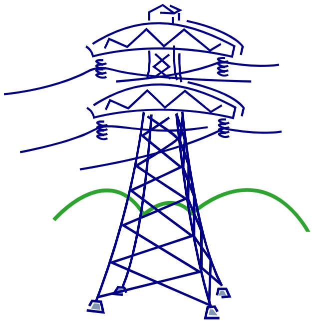
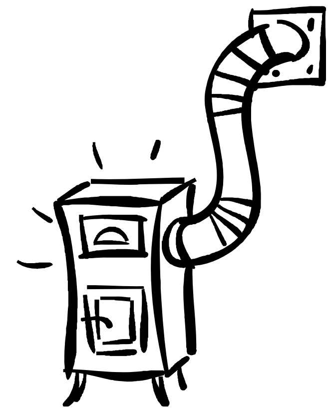
Geothermal Heat Pump Efficiency



1 unit of energy
from the grid

Yields:
4-6 units of energy
for the building



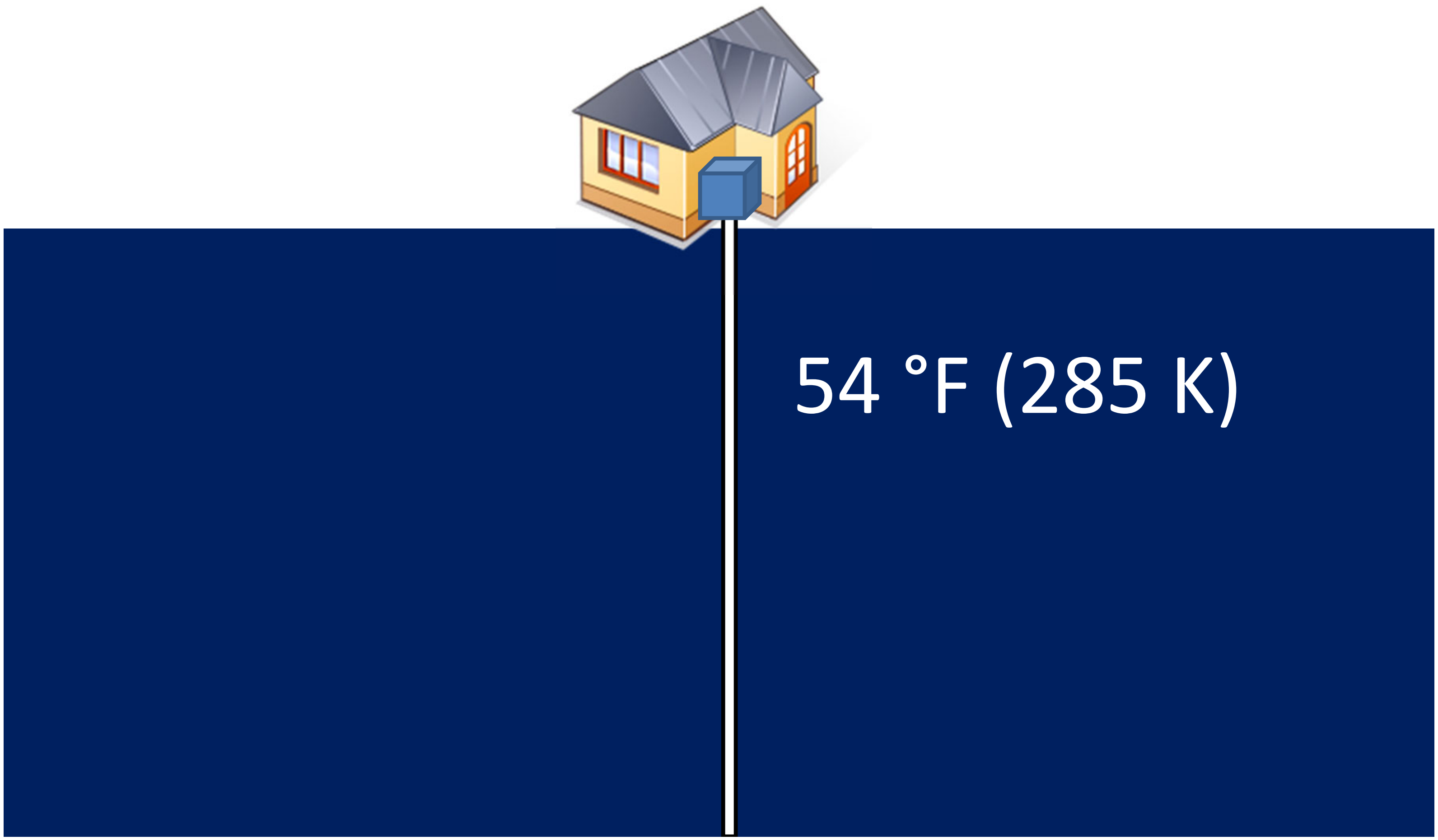
Plus:
3-5 units of "free"
energy from ground

400-600% "Efficient"

Is this sustainable?

(Bony, 2012)

Ground Response to GS Heat Pumps



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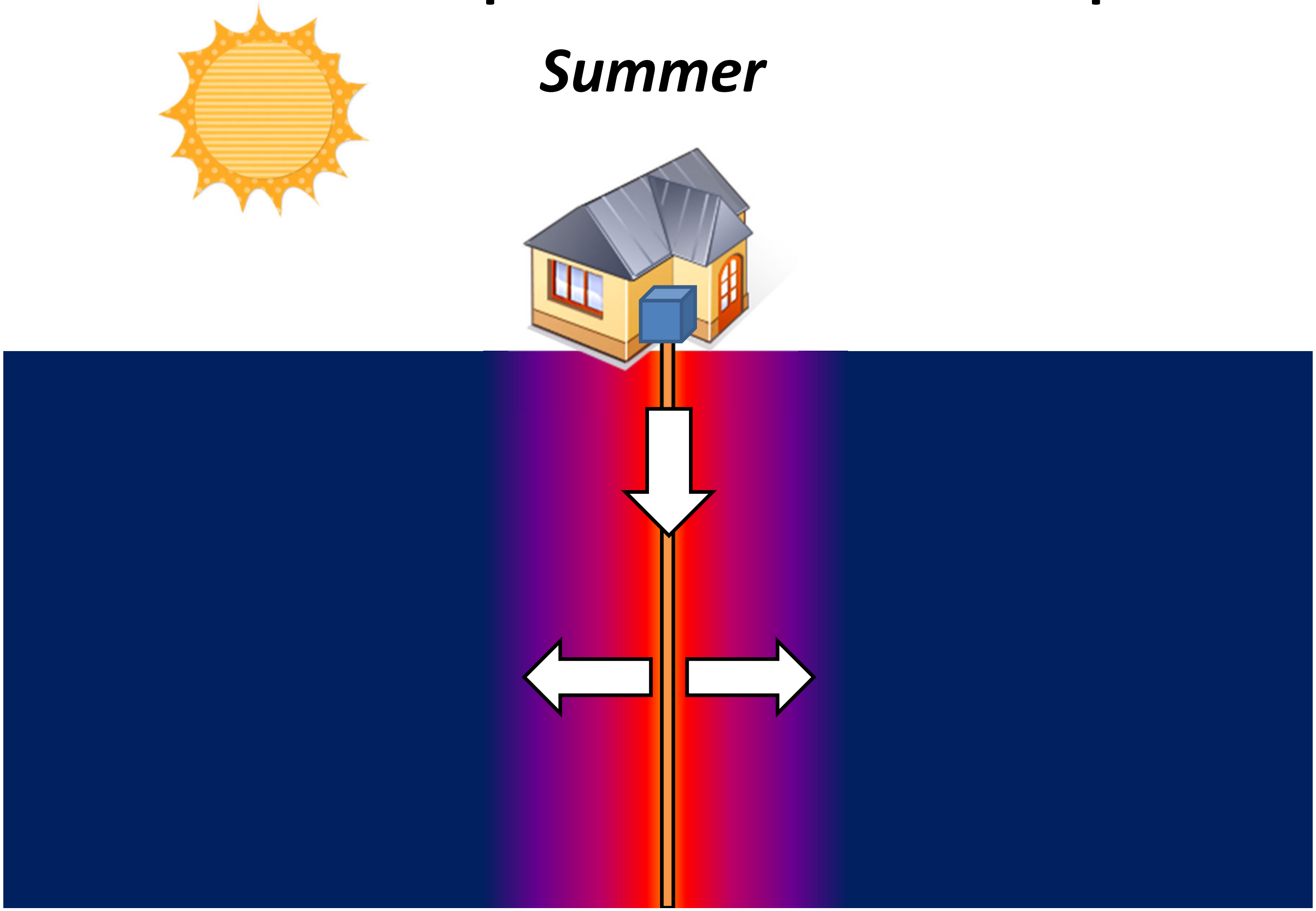
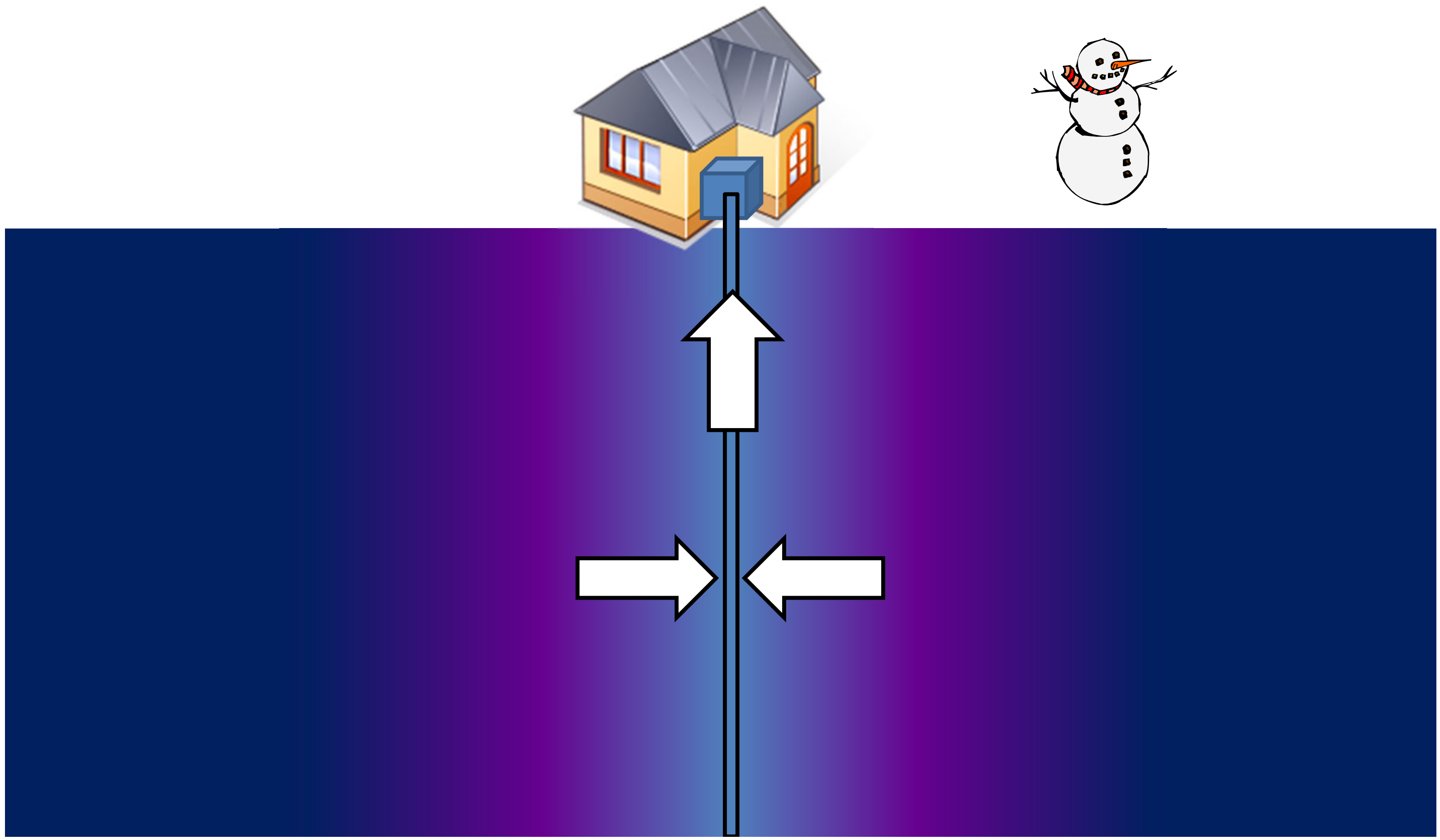
Ground Response to GS Heat Pumps

Summer



Ground Response to GS Heat Pumps

Winter



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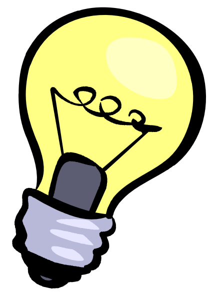
Fundamentals of Heat Transport

Heat Energy

J, joule, 1 kg m^2 s^{-2}

BTU, British Thermal Unit; 1 BTU raises 1 lb water 1 °F

1 BTU ≈ 1 kJ ≈ energy in a match



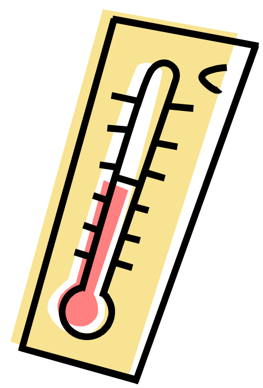
Heat Flow

W, watt, 1 W = 1 J s^{-1}

BTU/h, BTUs per hour

1 ton = 12,000 BTU/h; 2,000 lbs ice in 24 hrs

1 ton = 3.5 kW



Temperature

K, kelvin, °C above absolute zero

°F, degrees Fahrenheit

54 °F = 285 K

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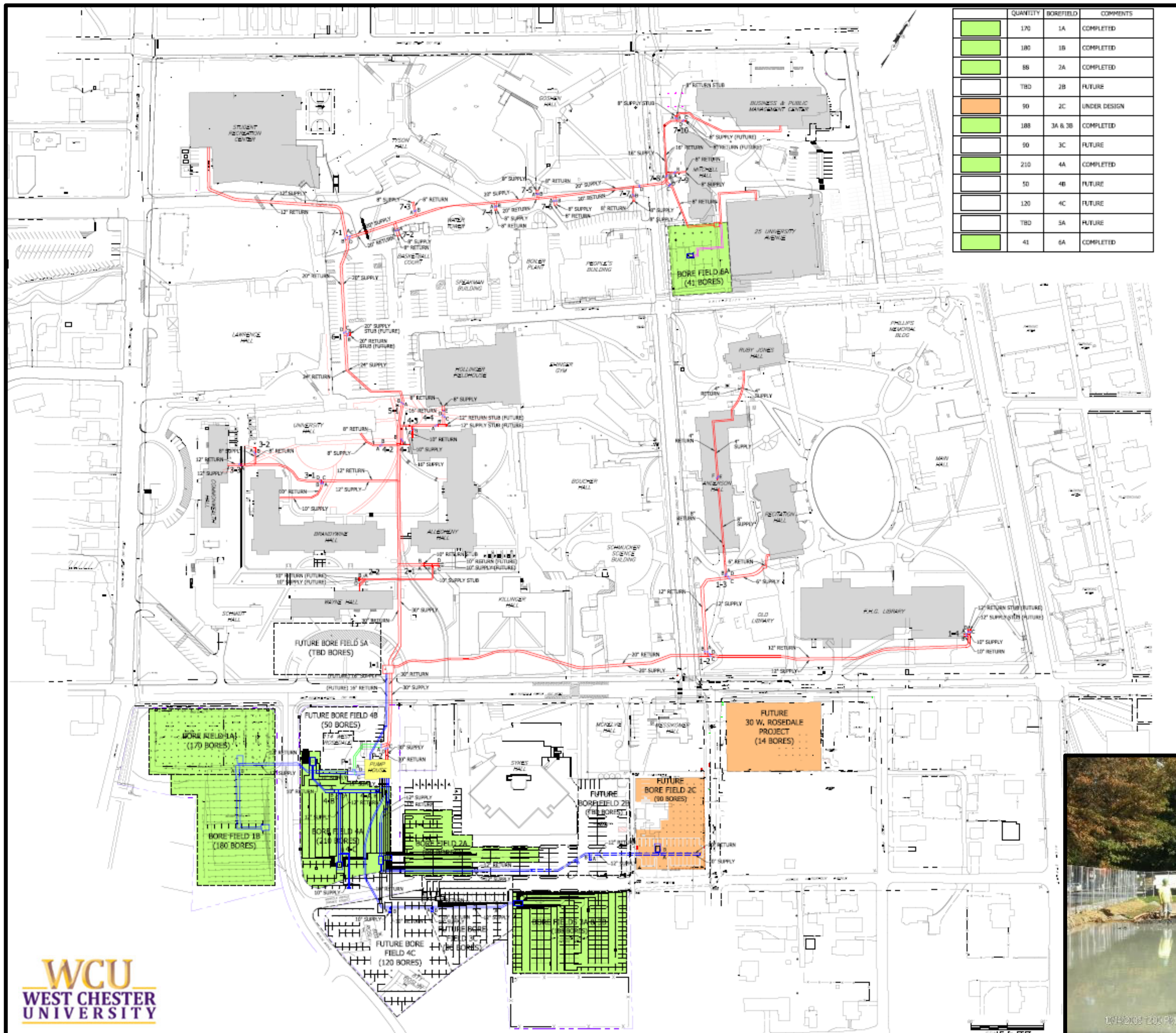
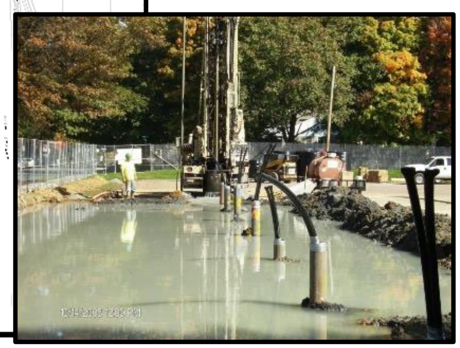
Geology

- Baltimore Gneiss Formation
- Felsic and mafic gneiss, metagranite and metadiabase
- Middle Proterozoic to Ordovician
- Fractured and heterogeneous

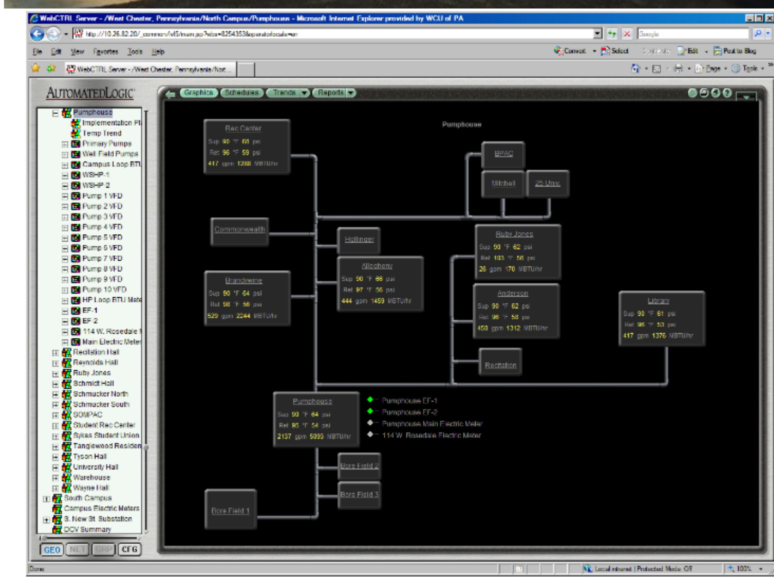
WCU's District Geothermal System

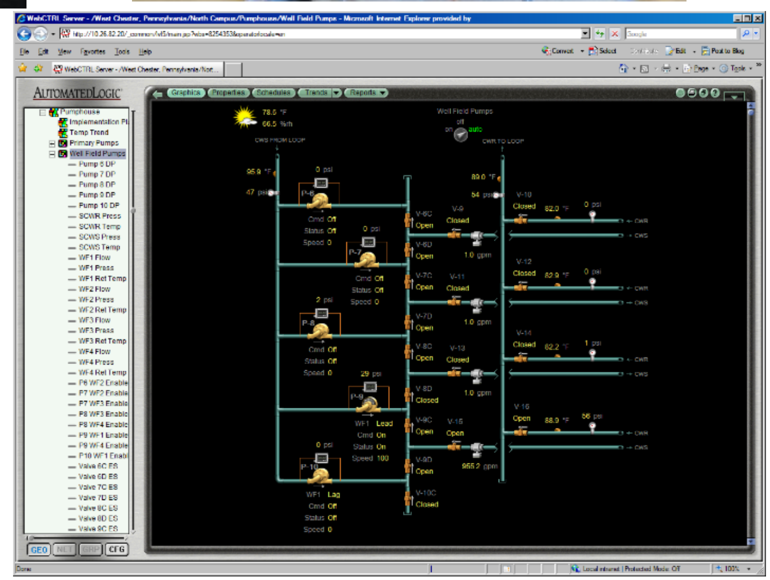
16.1 MW (4,600 ton)
$40M
1,400 (currently 836) wells
152m (500 ft) deep





WCU's Geothermal Pumphouse





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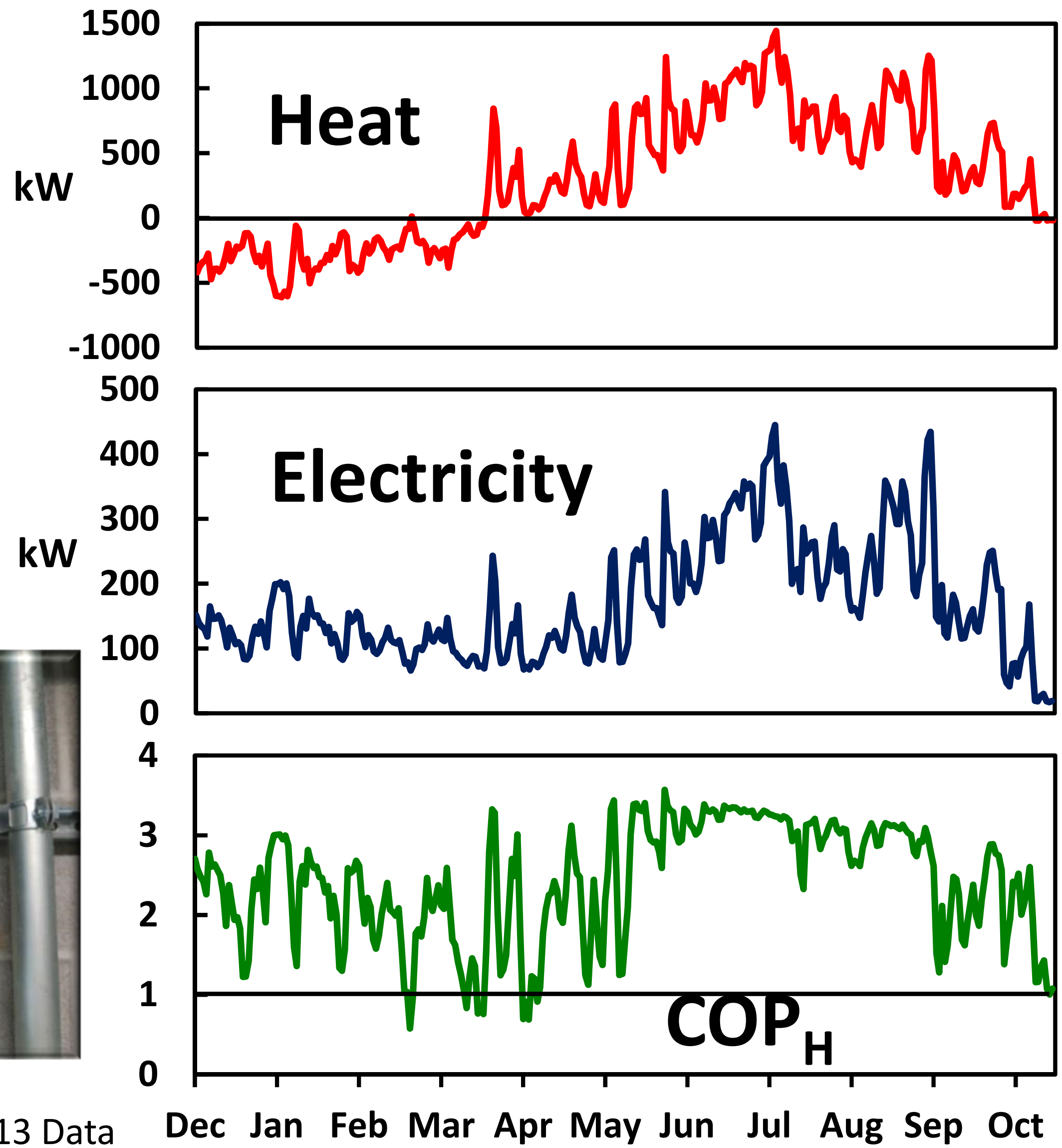
The WCU Geothermal System is Efficient



2012-2013 Data

$$COP_H = \frac{H}{E}$$

COP_H: coefficient of performance
H: heat extracted/injected (W)
E: electrical power (W)

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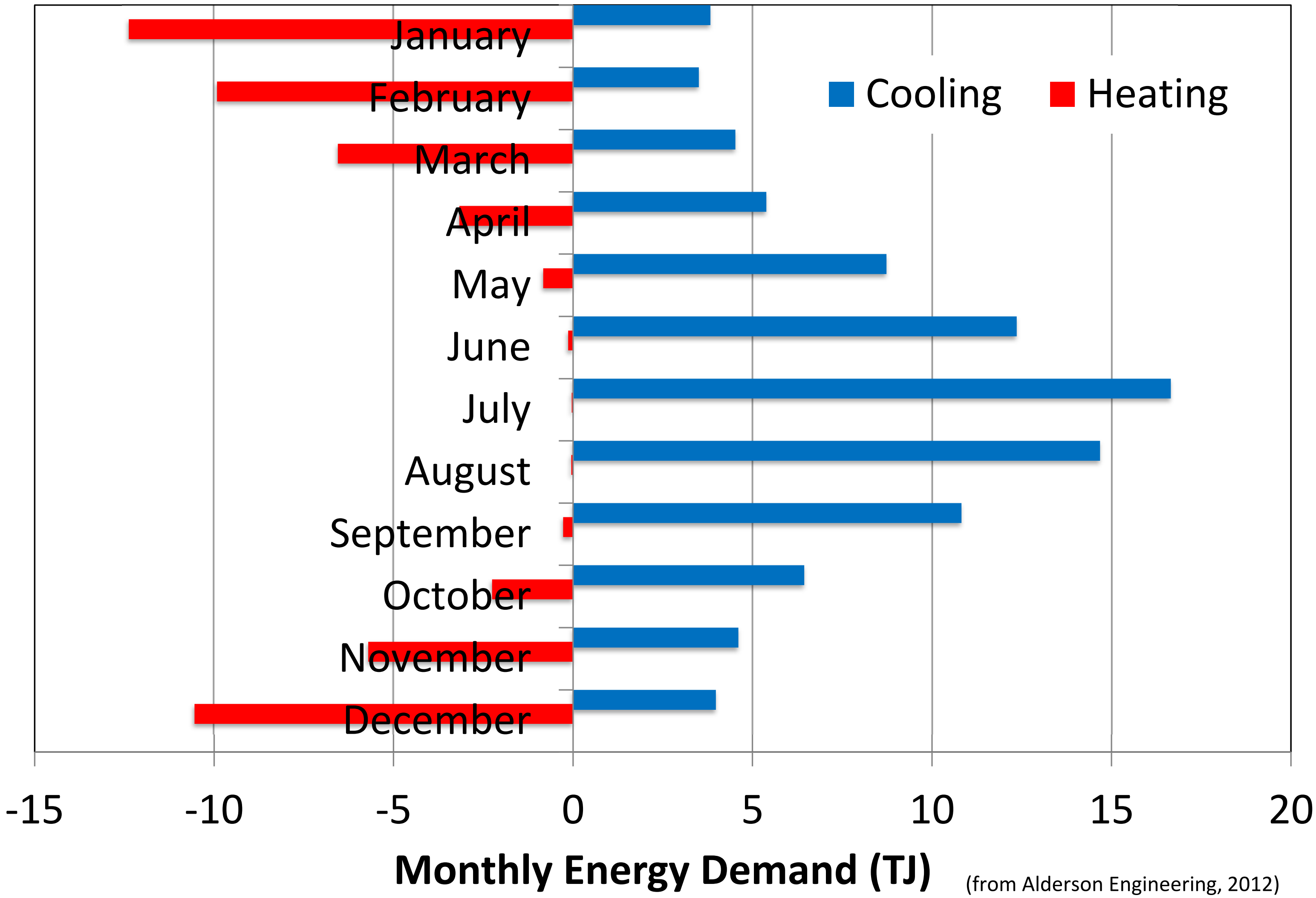
Total N Campus Load – 79% More Cooling than Heating



(from Alderson Engineering, 2012)

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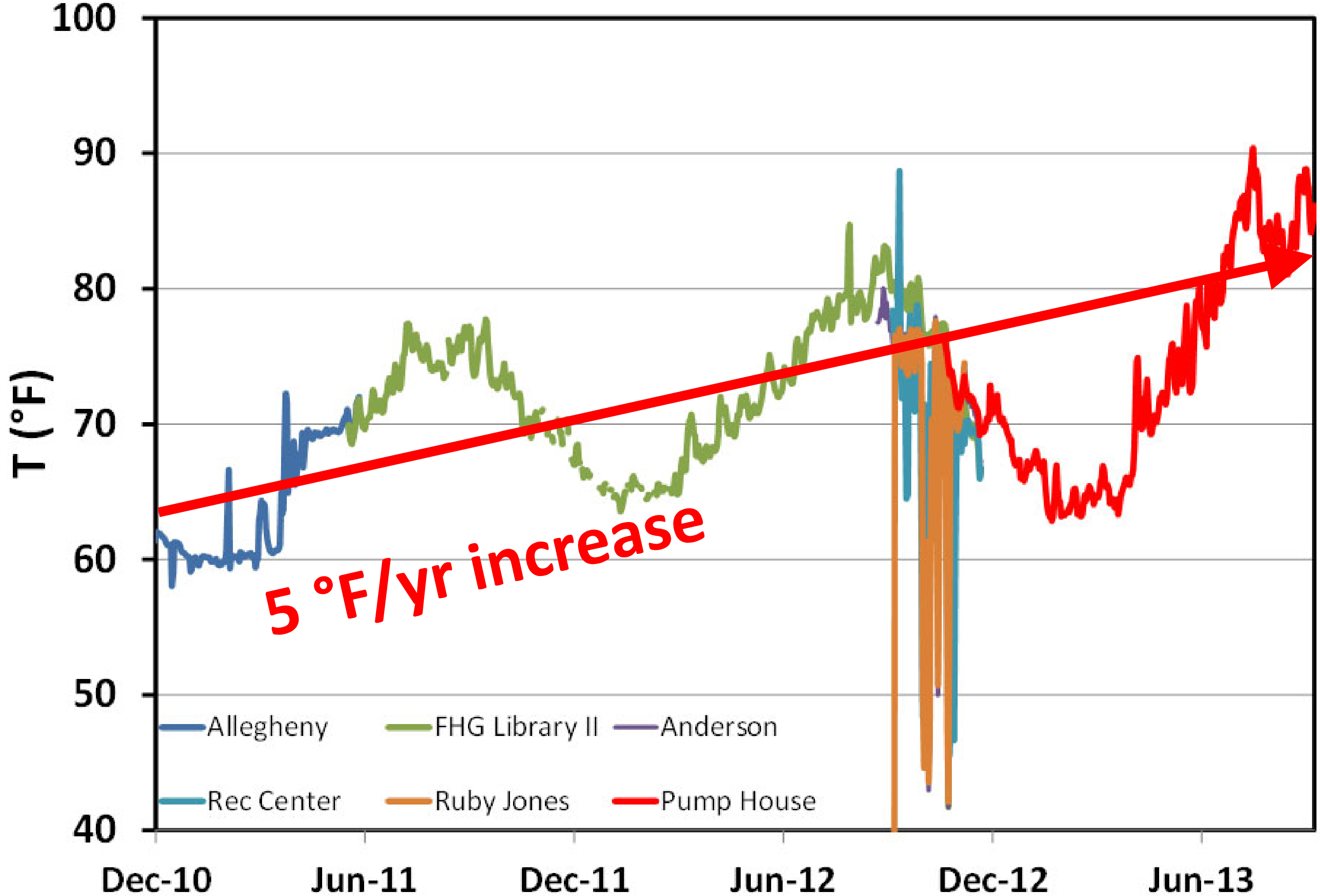
Each Person Produces 80-100 W Heat!

Geothermal Wellfield Return Temperature 2010 to 2013



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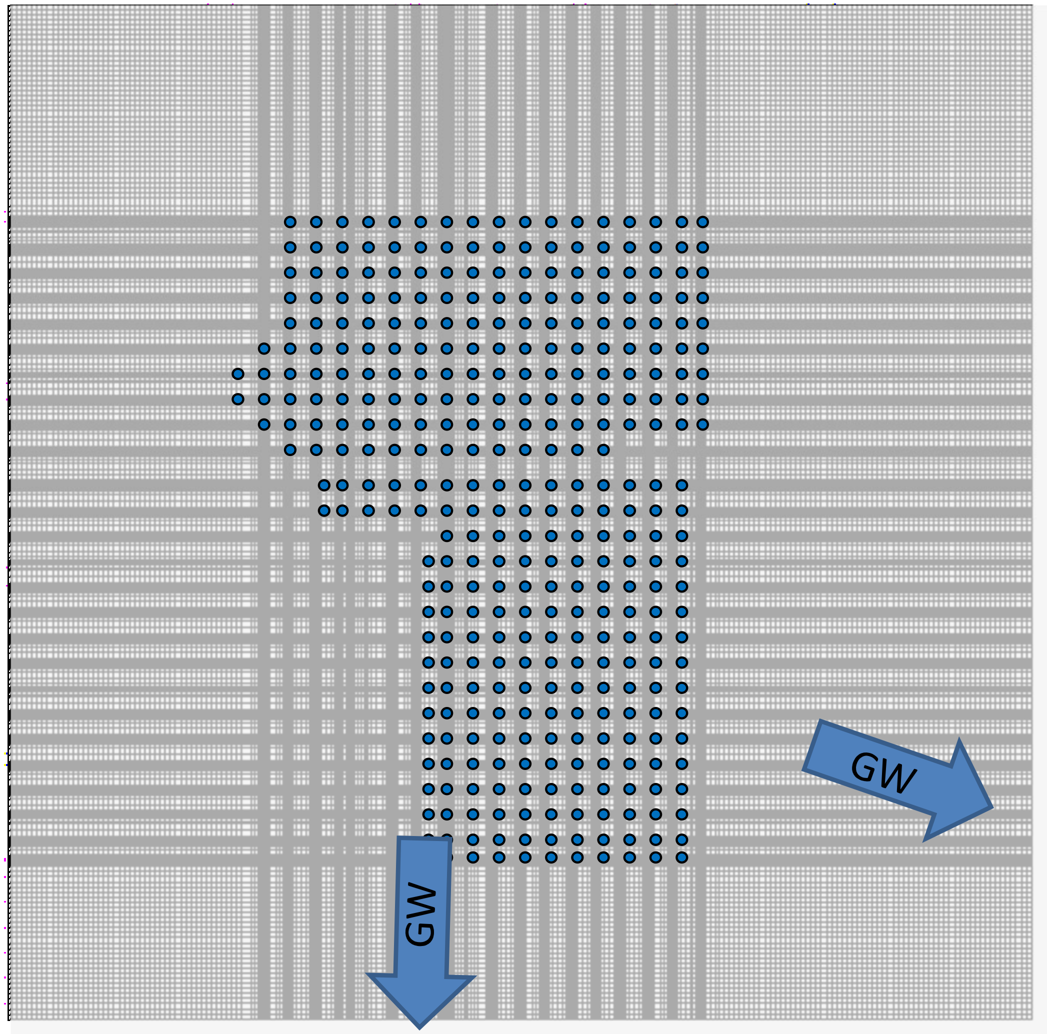
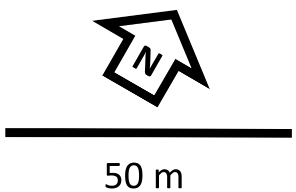
MODFLOW/MT3DMS Simulation of Thermal Response
Coupled heat and groundwater transport



K = 1 x 10^{-6} m/s
T_0 = 54 °F (285 K)
D_m = 1.4 x 10^{-6} m^2/s
K_d = 5.0 x 10^{-4} m^3/kg
ρ_B = 2,400 kg/m^3
R = 0.54 m/yr



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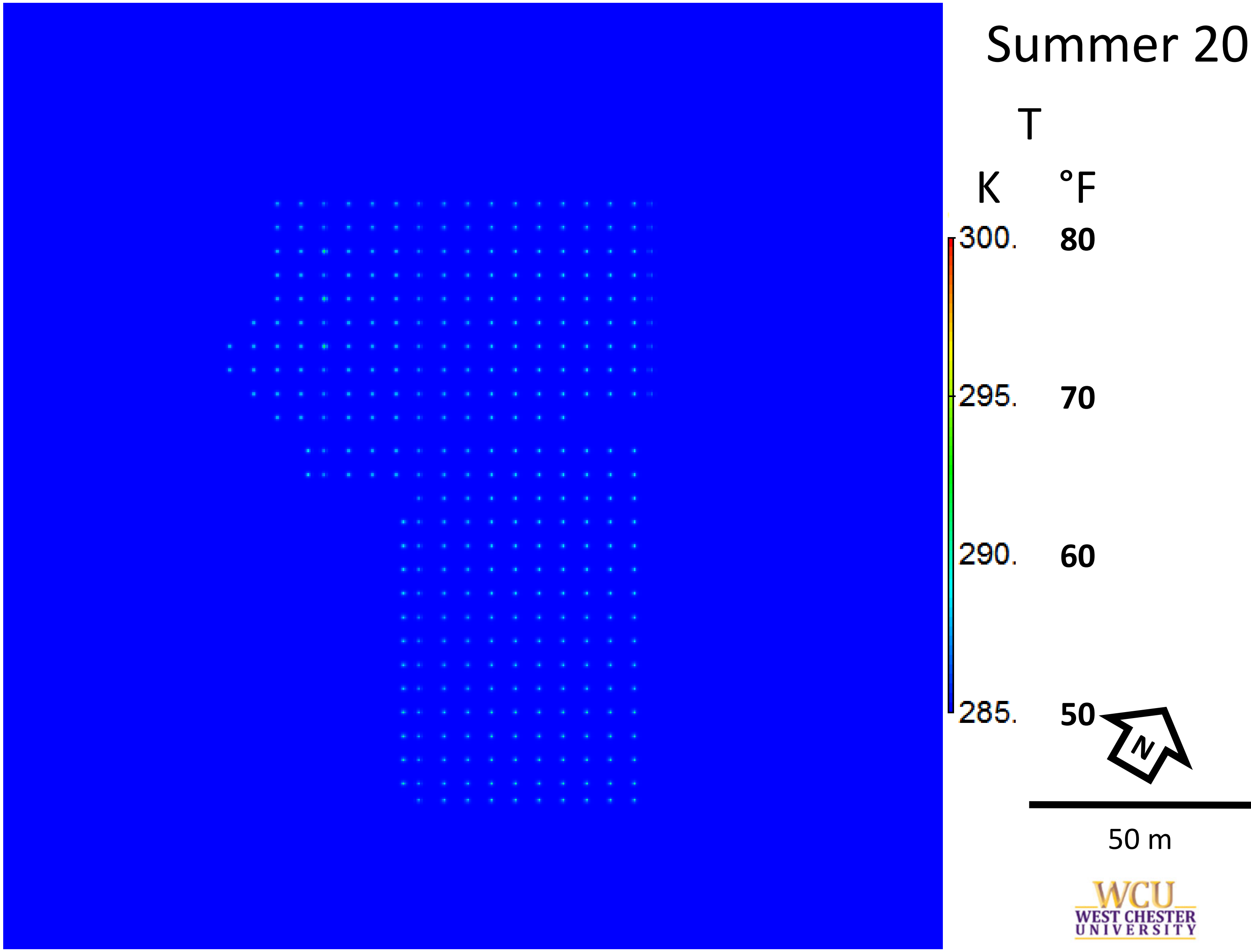
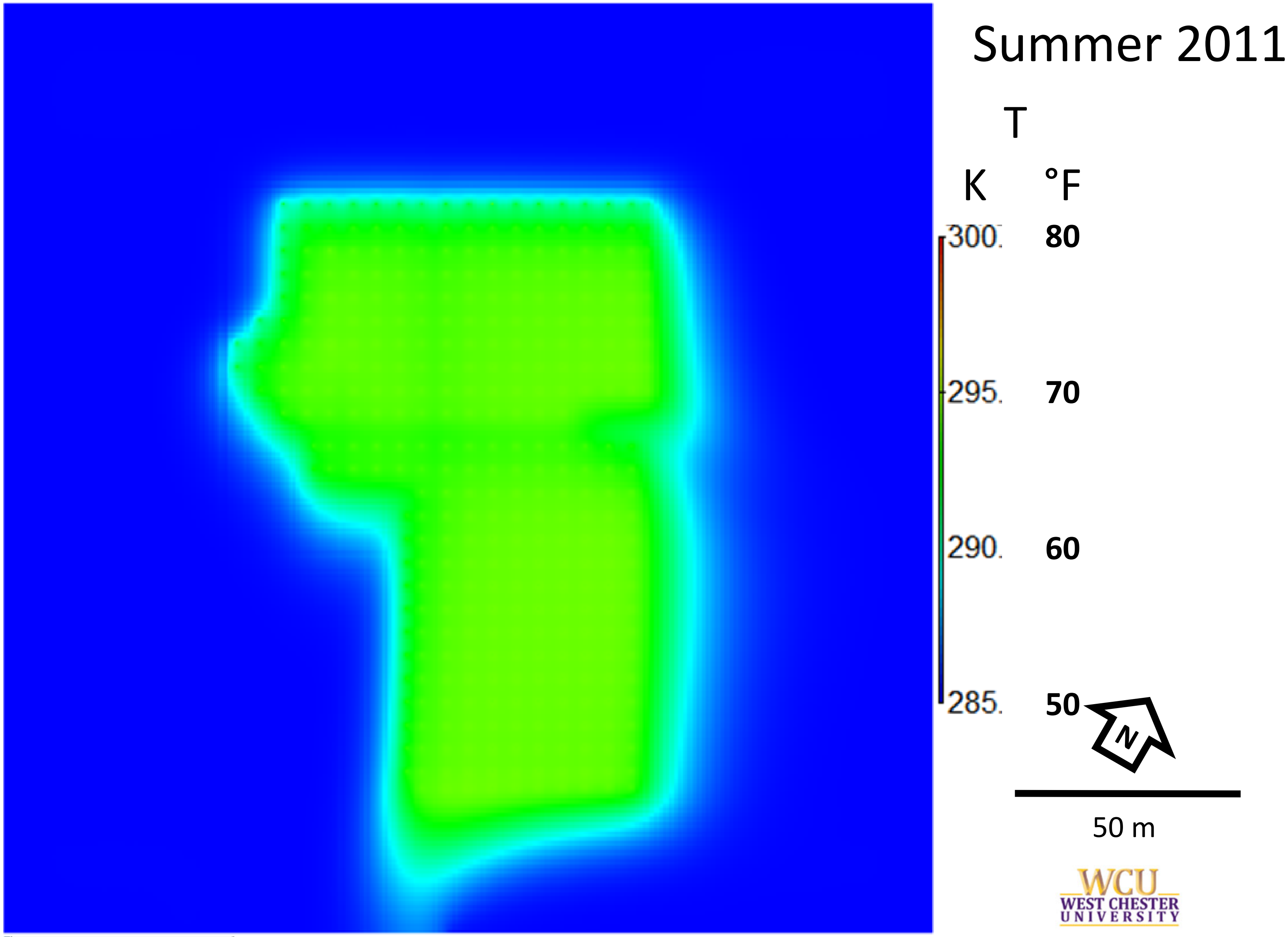
Summer 2010




Summer 2011
T
K
°F
300.
80
295.
70
290.
60
285.
50
N
50 m
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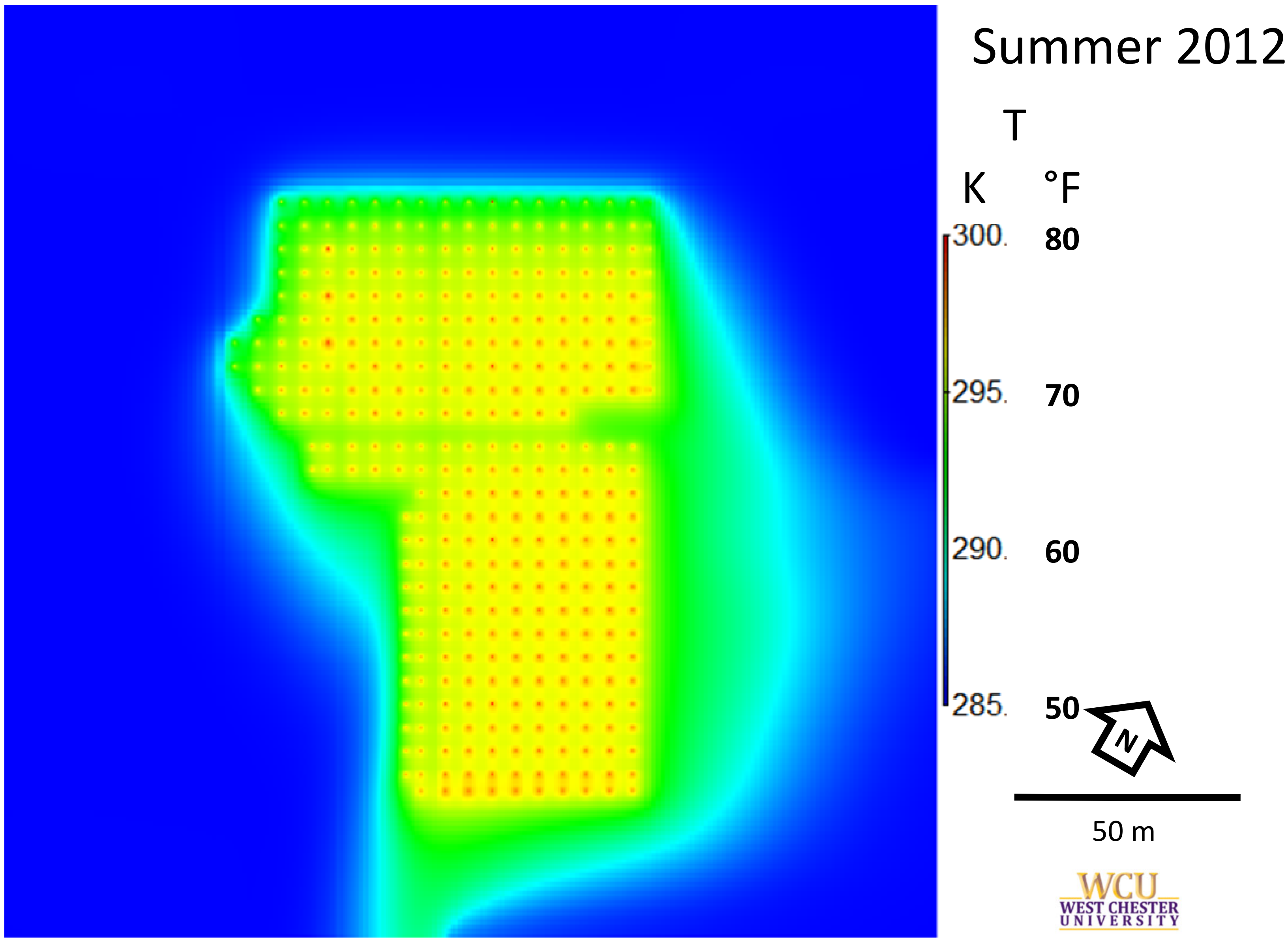

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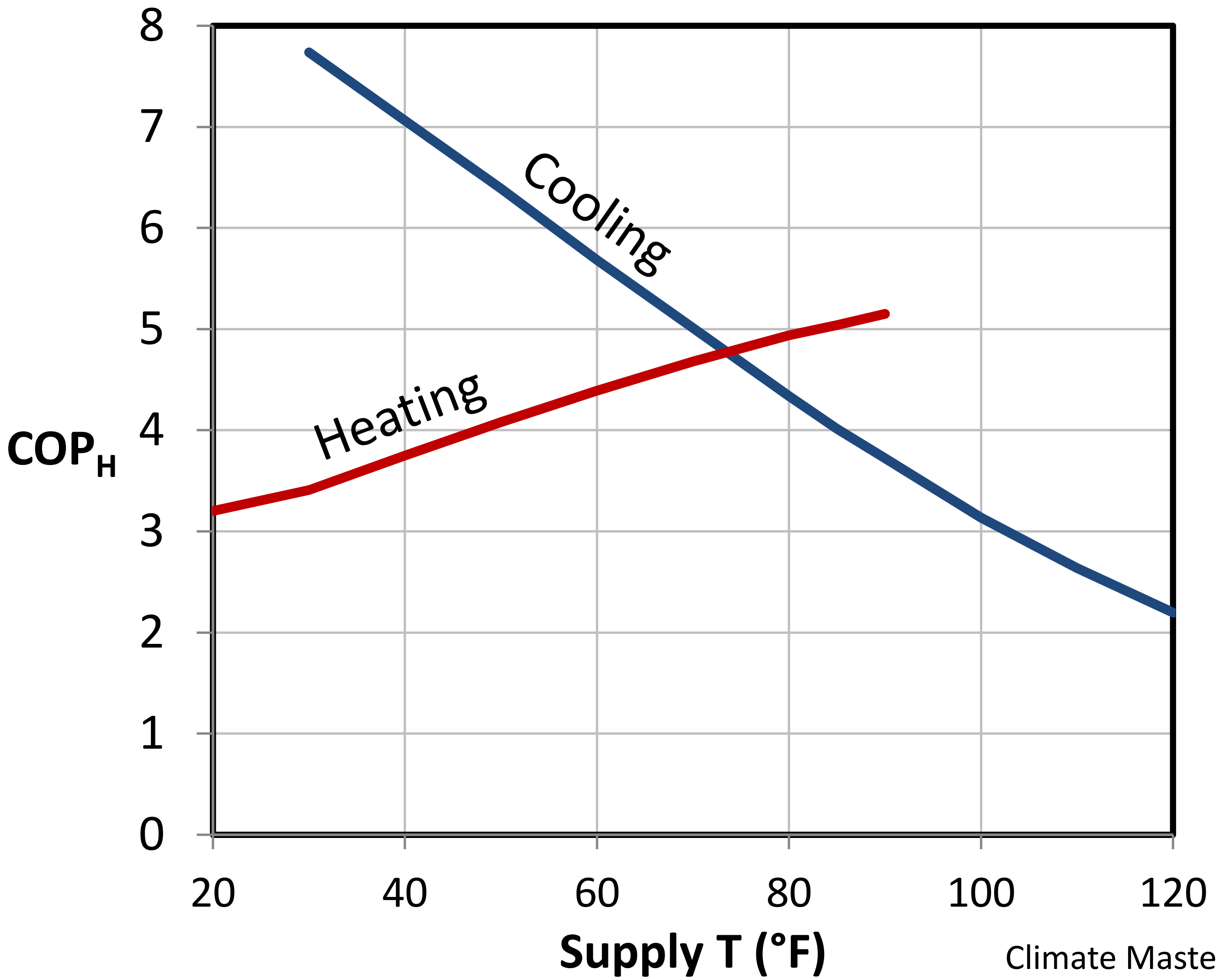
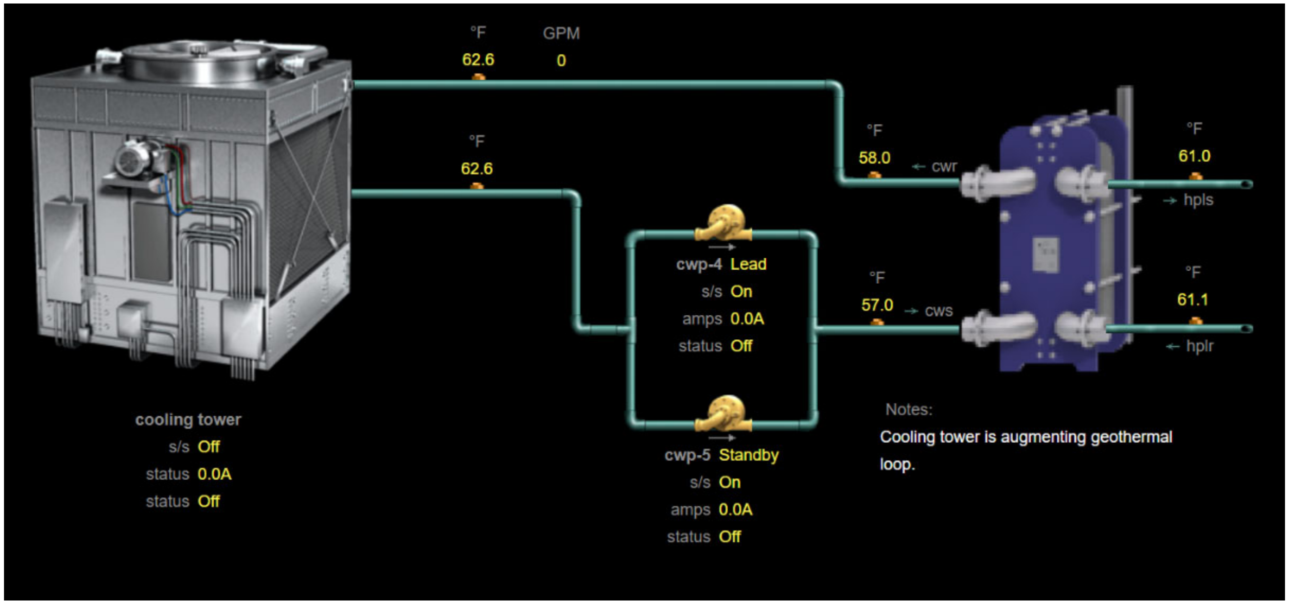
Heat Pump Efficiency



Climate Master, 2013

Geothermal Cooling Tower



Heat Removal
2019/2020: 1.2 TJ
2020/2021: 0.8 TJ

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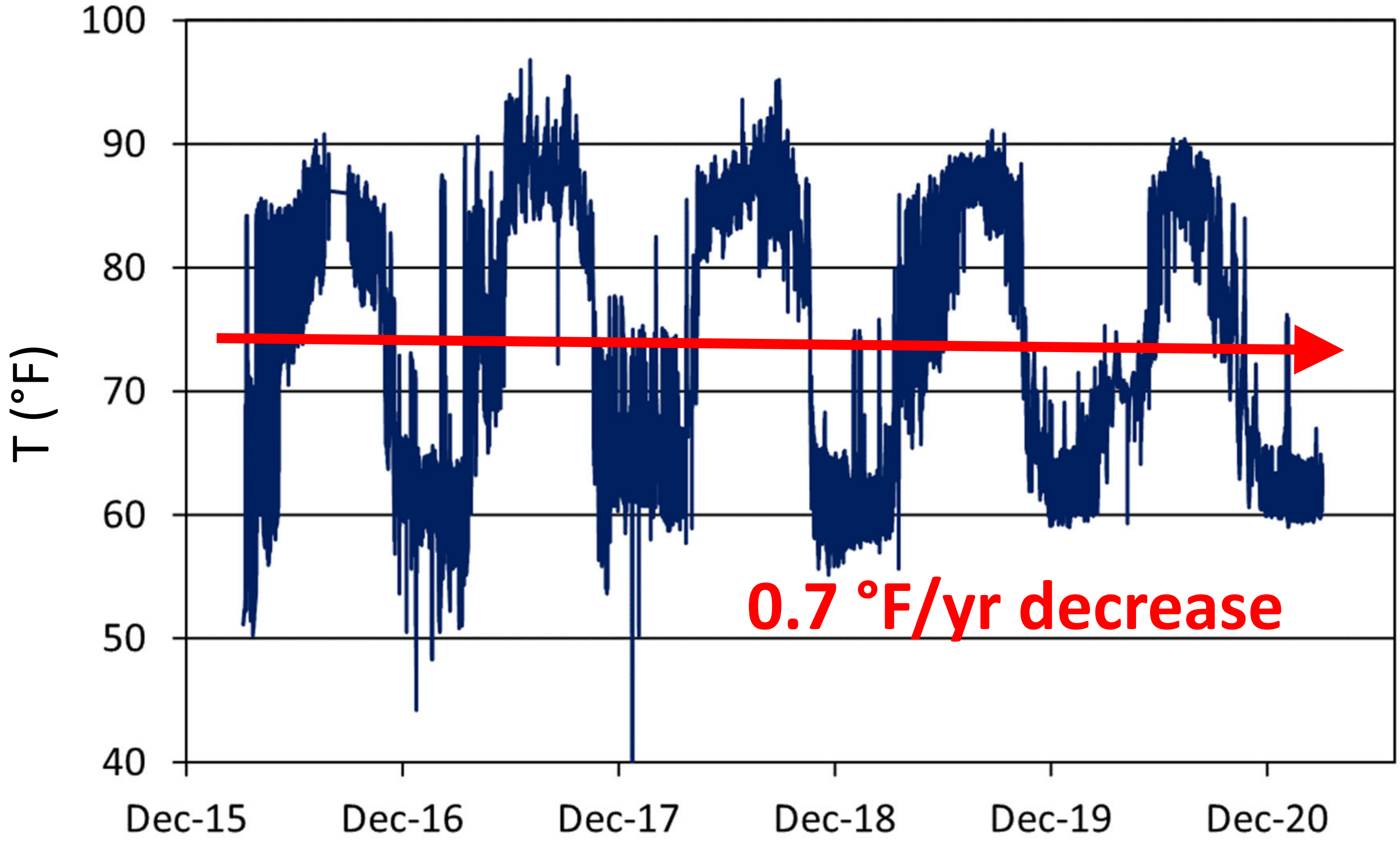
Geothermal Wellfield Return Temperature 2015 to 2021



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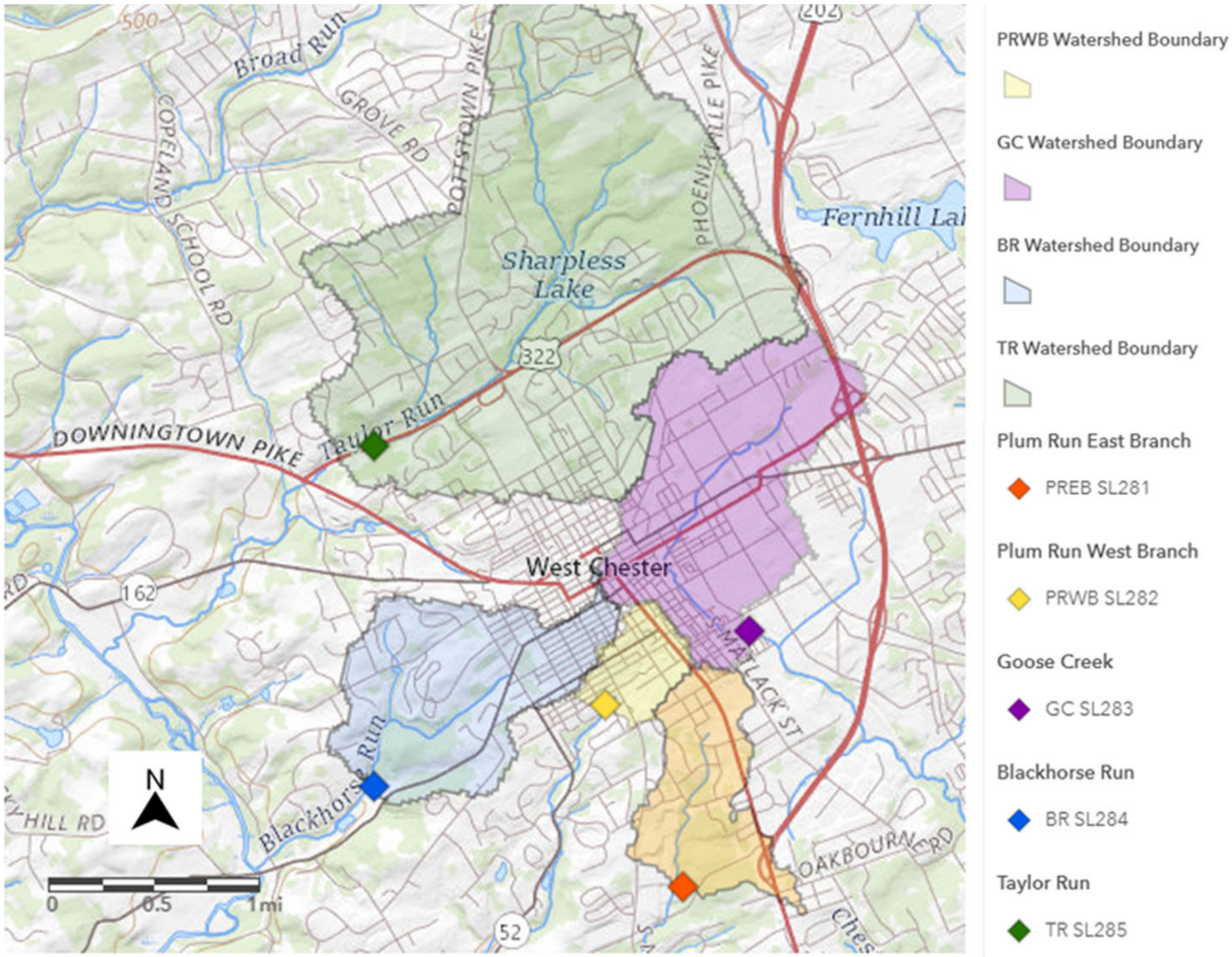
INVESTIGATING STREAM RESPONSE TO ROAD DE-ICING AGENTS

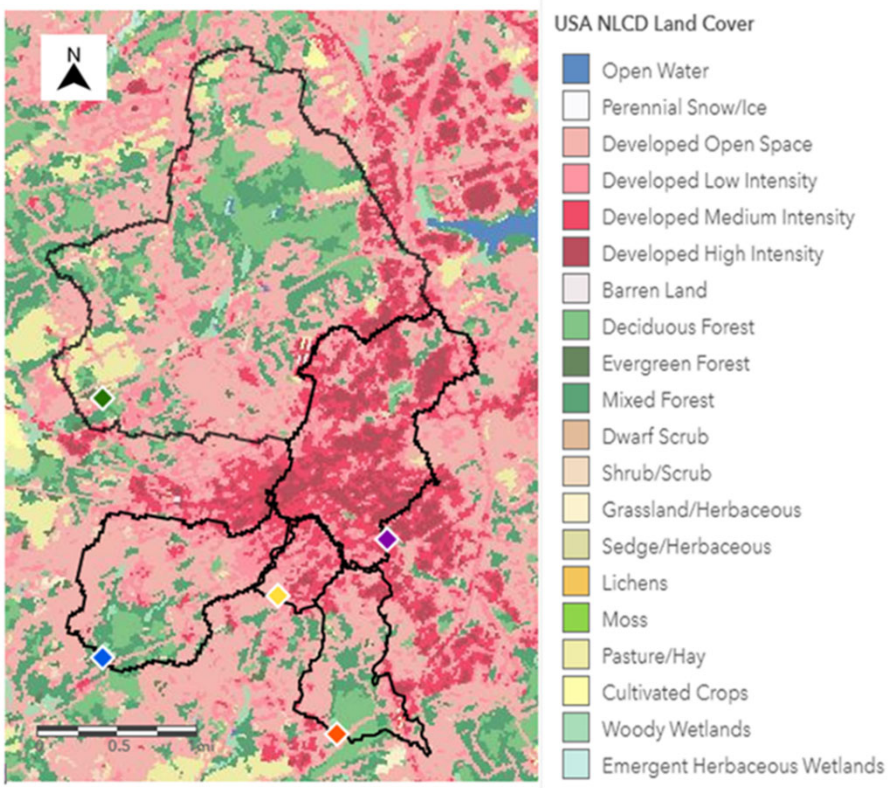
A CLOSER LOOK AT 5 STREAMS IN WEST CHESTER, PENNSYLVANIA



PRWB Watershed Boundary
GC Watershed Boundary
BR Watershed Boundary
TR Watershed Boundary
Plum Run East Branch
PREB SL281
Plum Run West Branch
PRWB SL282
Goose Creek
GC SL283
Blackhorse Run
BR SL284
Taylor Run
TR SL285
West Chester
Sharpless Lake
Fernhill Lake
DOWNINGTOWN PIKE
Taylor Run
Broad Run
Blackhorse Run
N
0
0.5
1mi

STUDY AREA

METHODS / LAND COVER



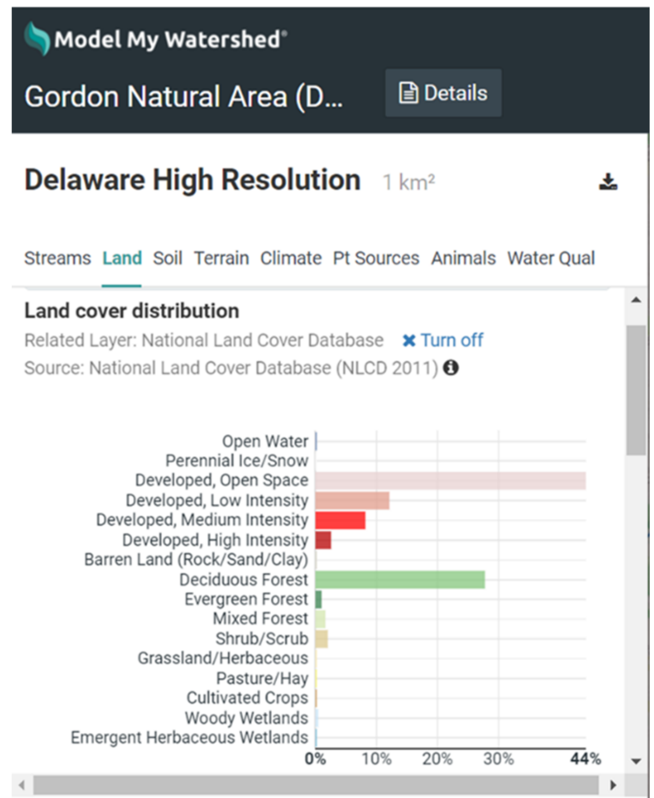


Image of Model My Watershed. Adapted from Model My Watershed, by SWRC, 2020, retrieved from https://modelmywatershed.org/project/31761/scenario/54611

METHODS / MONITORING STATION INSTALLATION

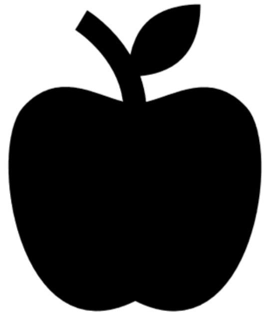
Left: David Bressler and Rachel Johnson

Right: Rachel Johnson, Shannon Hicks, and David Bressler


95
90
85
80
75
70
65
60
55
50
45
40
35
30
25

METHODS

DISCHARGE MEASUREMENTS



Neutral Buoyant Object (NBO)

$Q(h) = ah^2+bh+c$, *where* h = *sensor depth*

METHODS / PRECIPITATION DATA

USGS 01480870 East Branch Brandywine Creek below Downingtown, PA

PROVISIONAL DATA SUBJECT TO REVISION

Available data for this site Time-series: Current/Historical Observations GO

Click to hide station-specific text

Funding for this site is provided by:

Chester County Water Resources Authority

USGS - Federal Priority Streamgages

USGS - Cooperative Matching Funds

Image of National Water Information Systems: Web Interface, by USGS. Retrieved from https://nwis.waterdata.usgs.gov/pa/nwis/uv/?cb_00045=on&format=gif_default&site_no=01480870&period=&begin_date=2019-12-09&end_date=2019-12-10

METHODS

CHLORIDE

RESULTS / EVENT #1
NO SALT

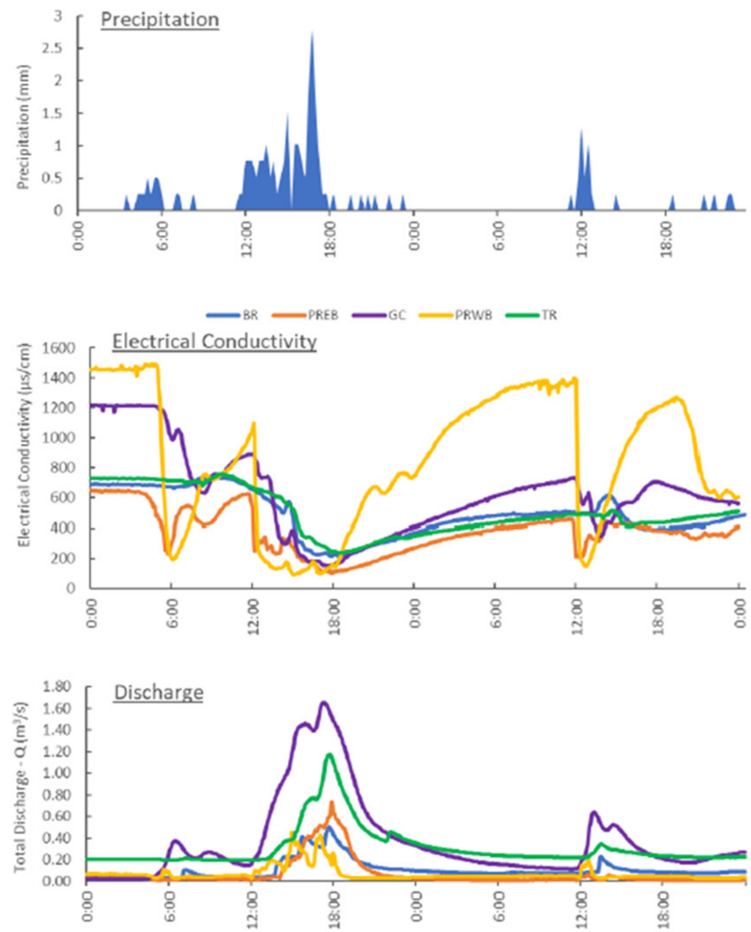
December 8 & 9, 2020

Precipitation

- 32 mm

Electrical Conductivity / Drop

Stream	From µS/cm	To µS/cm
PREB	604	230
PRWB	1449	194
GC	1208	631
TR	727	238
BR	468	219



RESULTS / EVENT #2

SALT RESPONSE

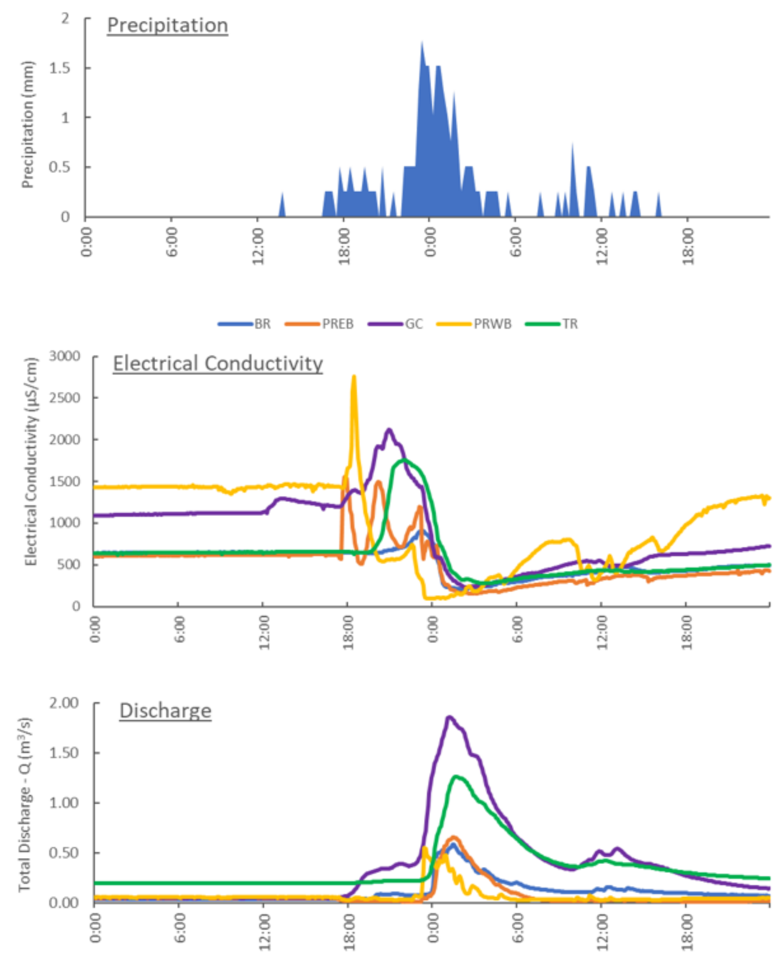
December 16 & 17, 2020

Precipitation

- 31 mm

Electrical Conductivity / Spike

Stream	From µS/cm	To µS/cm
PREB	605	1551
PRWB	1428	2764
PREB	605	1482
GC	1092	2126
TR	638	1755
PREB	605	1195
BR	639	907



RESULTS / EVENT #3
RESIDUAL SALT RESPONSE (?)

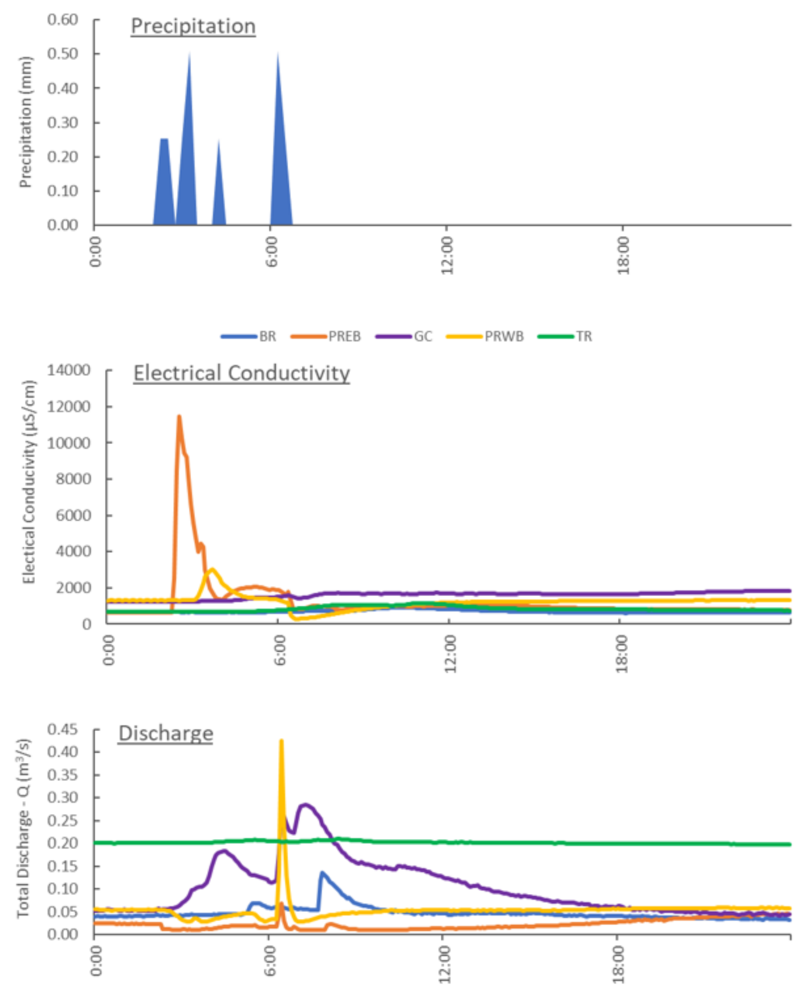
January 12, 2020

Precipitation

- 2.3 mm

Electrical Conductivity / Spike

Stream	From µS/cm	To µS/cm
PREB	641	11444
PRWB	1279	3012
GC	1225	1859
TR	689	1148
BR	665	910



RESULTS / EVENT #4

SALT RESPONSE

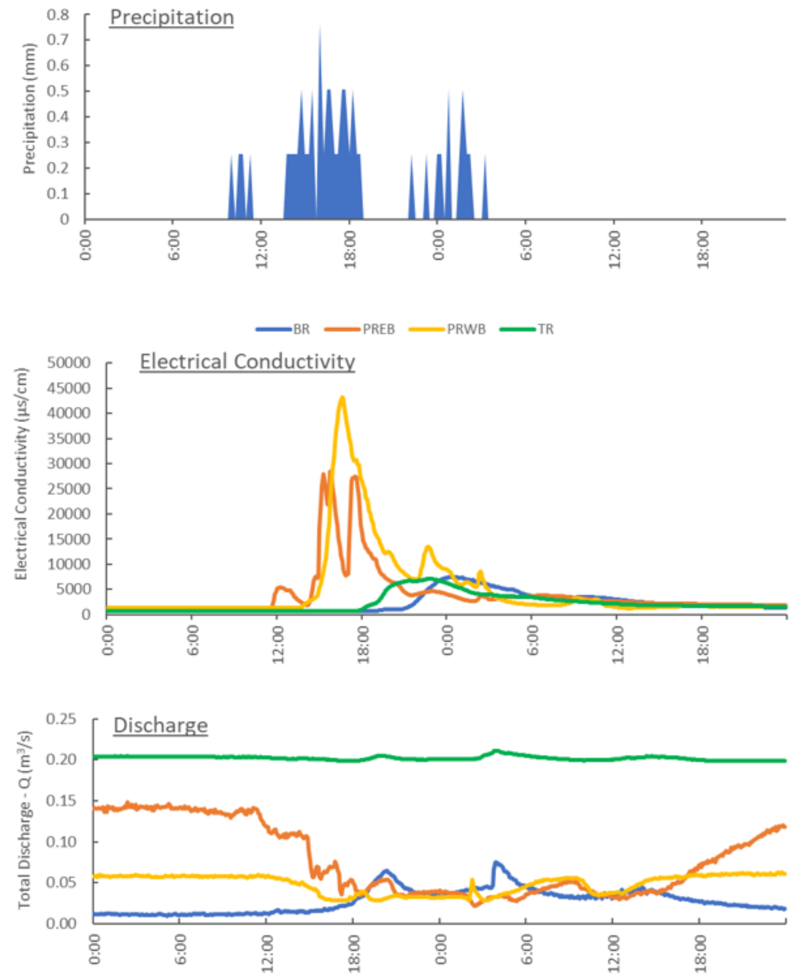
January 18 & 19, 2020

Precipitation

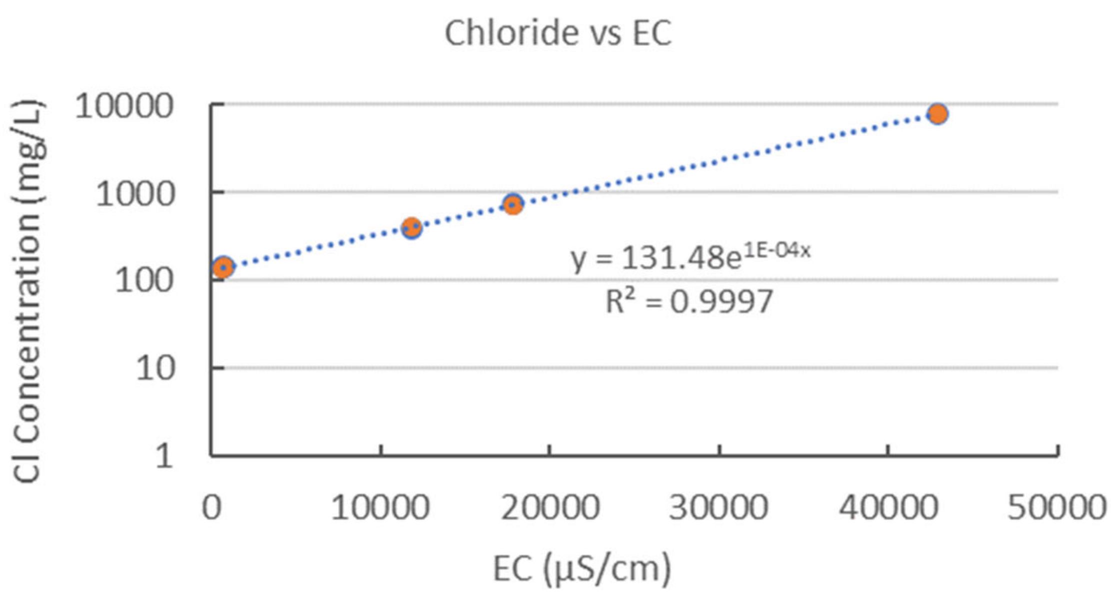
- 11 mm

Electrical Conductivity / Spike

Stream	From µS/cm	To µS/cm
PREB	695	5381
PREB	695	27990
PRWB	1320	43287
PREB	696	28430
PREB	695	27473
PRWB	1320	8559
PRWB	1320	13437
TR	740	7083
BR	694	7476



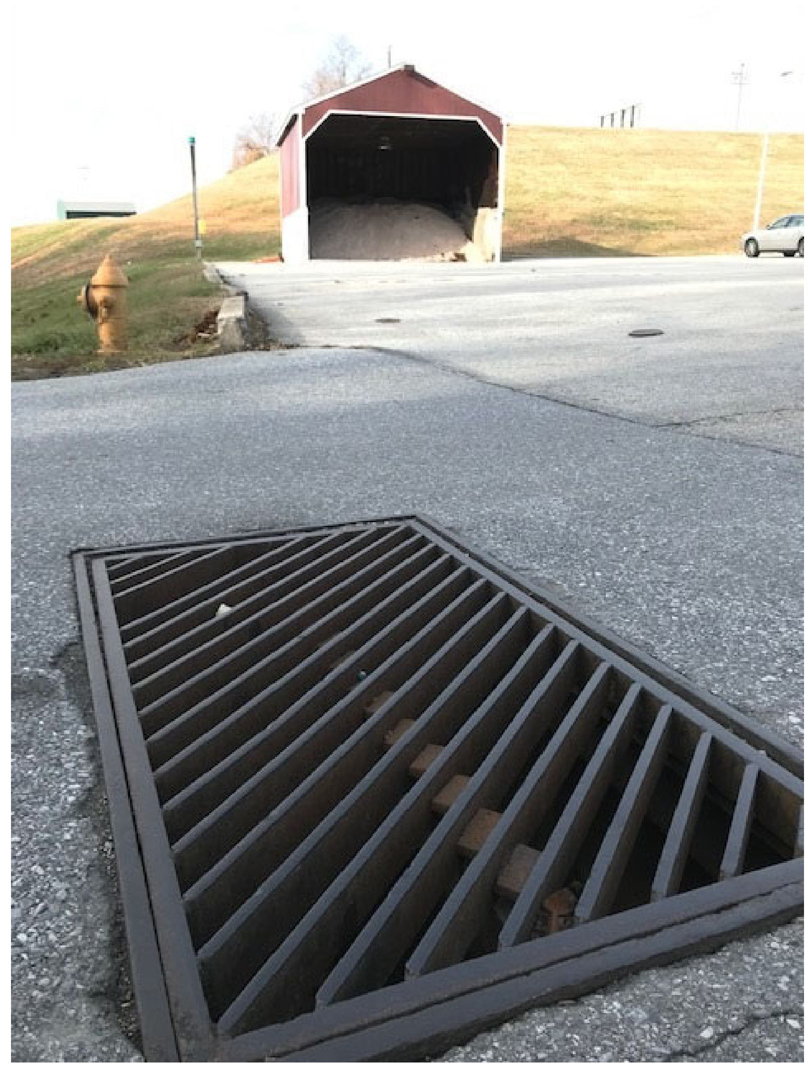
RESULTS / CHLORIDE



CONCLUSION

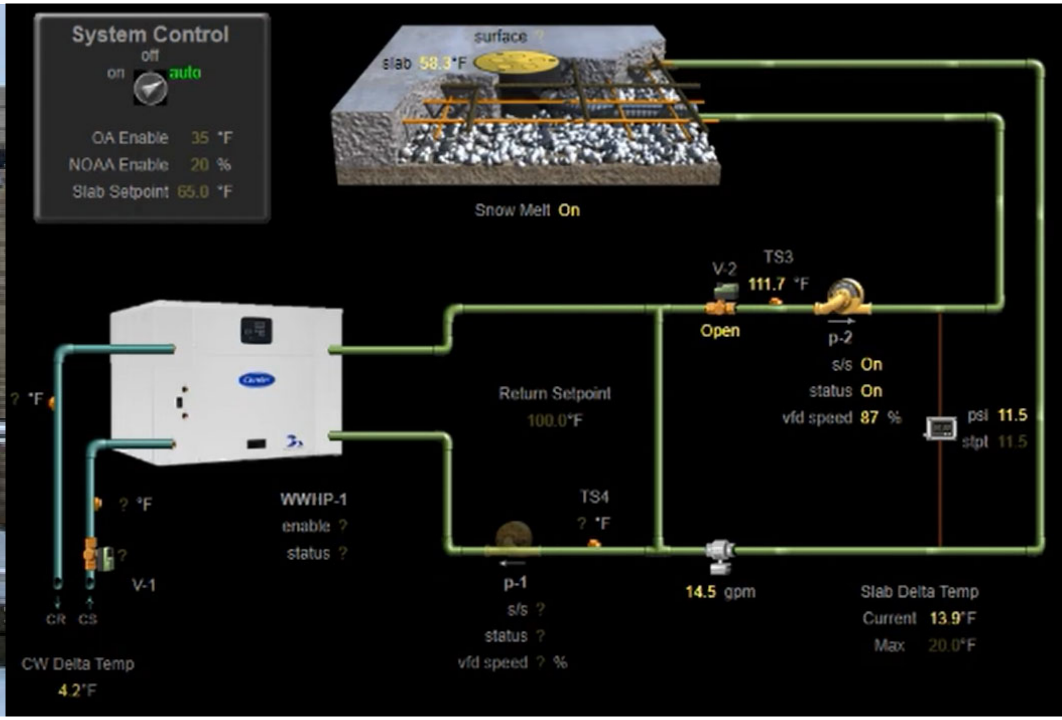
- Stream responses to de-icing agents were identified as a result of observing baseline data for this study.
  - PREB and PRWB are the first two streams to respond to de-icing agents observed as spikes in EC.
  - GC is typically the third stream to reach peak EC. GC experiences a slower steadier rise.
  - TR and BR are the fourth and fifth streams to reach peak EC, respectively. These streams also experience a slow steady rise, reaching peak EC several hours after the first responses of PREB and PRWB.
- De-icing agents may have significant impacts on aquatic life and the potability of water. Long term research will be necessary to identify specific effects and develop mitigating measures to assure the future health of these freshwater sources.

Thermal UAS
Heated Sidewalk Pilot
Project



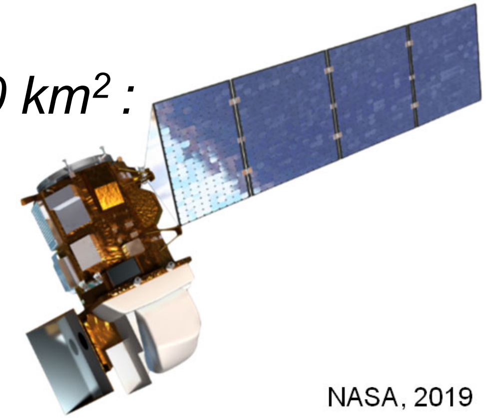
Thermal UAS Heated Sidewalk Pilot Project

- *Front Mezzanine of 25 University Hall*
- *Installed in 2008*
- *>283 m of hydronic tubing over 90 m^2*
- *Releases 28.7 kW heat*



Scales of Remote Sensing

>100,000 km^2 :
Satellite



NASA, 2019

100-100,000 km^2:
Conventional aircraft

WADNR, 2019

0.1 to 100 km^2 :
sUAS

<0.1 km^2 :
Hand-held camera

Select the correct scale of analysis for your investigation

UAV Sensor Technologies

- ***Cameras***
  - Electro-Optical (EO)
  - Zoom
  - Thermal IR
  - Multispectral/Hyperspectral
  - IR Gas Detection
- ***Lasers***
  - LiDAR
  - Laser gas detection
- ***Geophysical instruments***
  - Magnetometer
  - EM
  - GPR
- **RAD: Geiger-Mueller, γ-Spec.**
- ***Gas Analyzers***
  - Solid state gas meter (O_2, H_2S, CO, LEL, Cl_2, NH_4, etc.)
  - PID/VOCs
  - GCMS
- ***Drone-deployed sensors***

Fort Collins, CO HazMat UAV (Rhode, 2018)

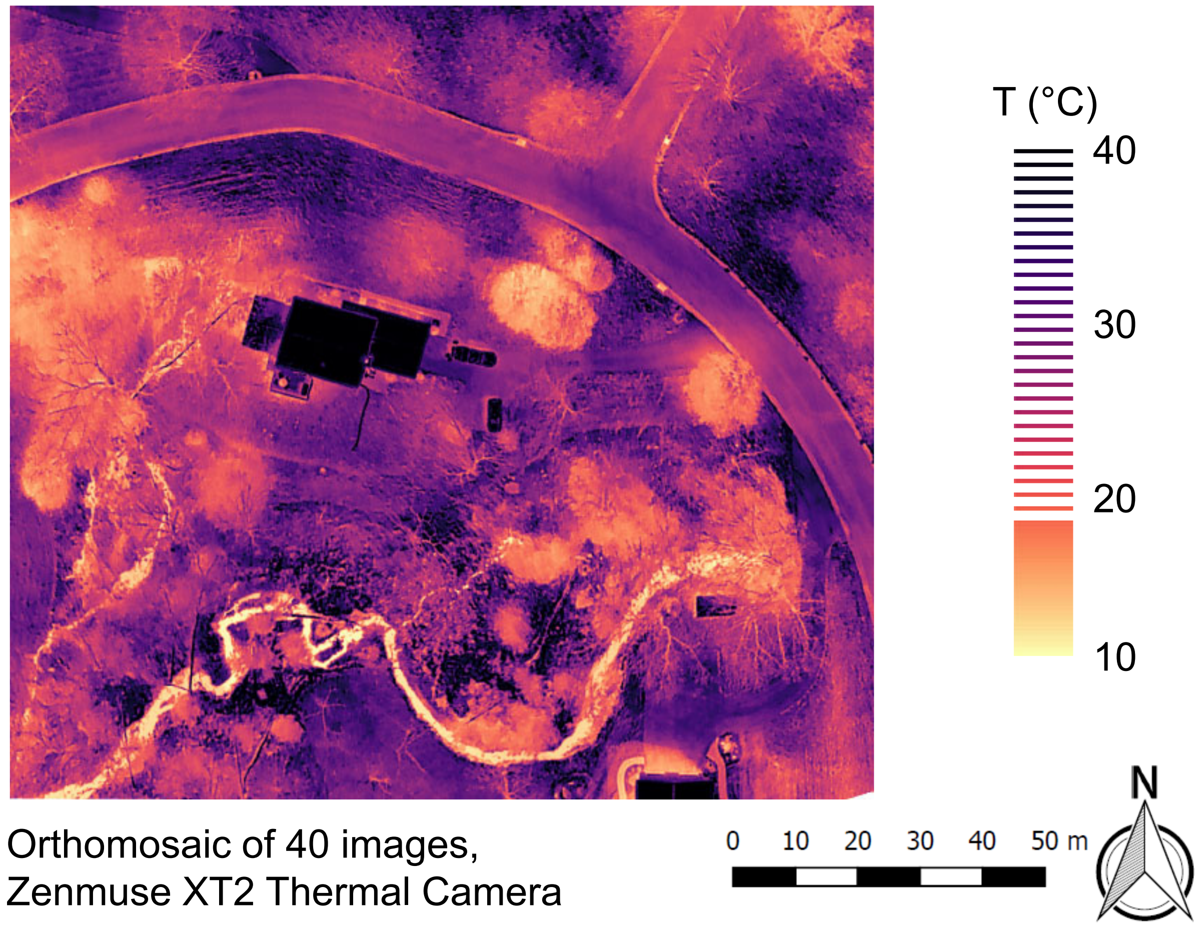
To select the right tool for the job, we must fully understand proper application, deployment, and analysis

Thermal IR Measures Temperature of Surfaces

Zenmuse XT2 Camera

- Far IR 15-1,000 μm
- FIIR Duo R
- 13 mm lens
- 640 x 520 pixels
- 30 fps
- 0.1 °C precision

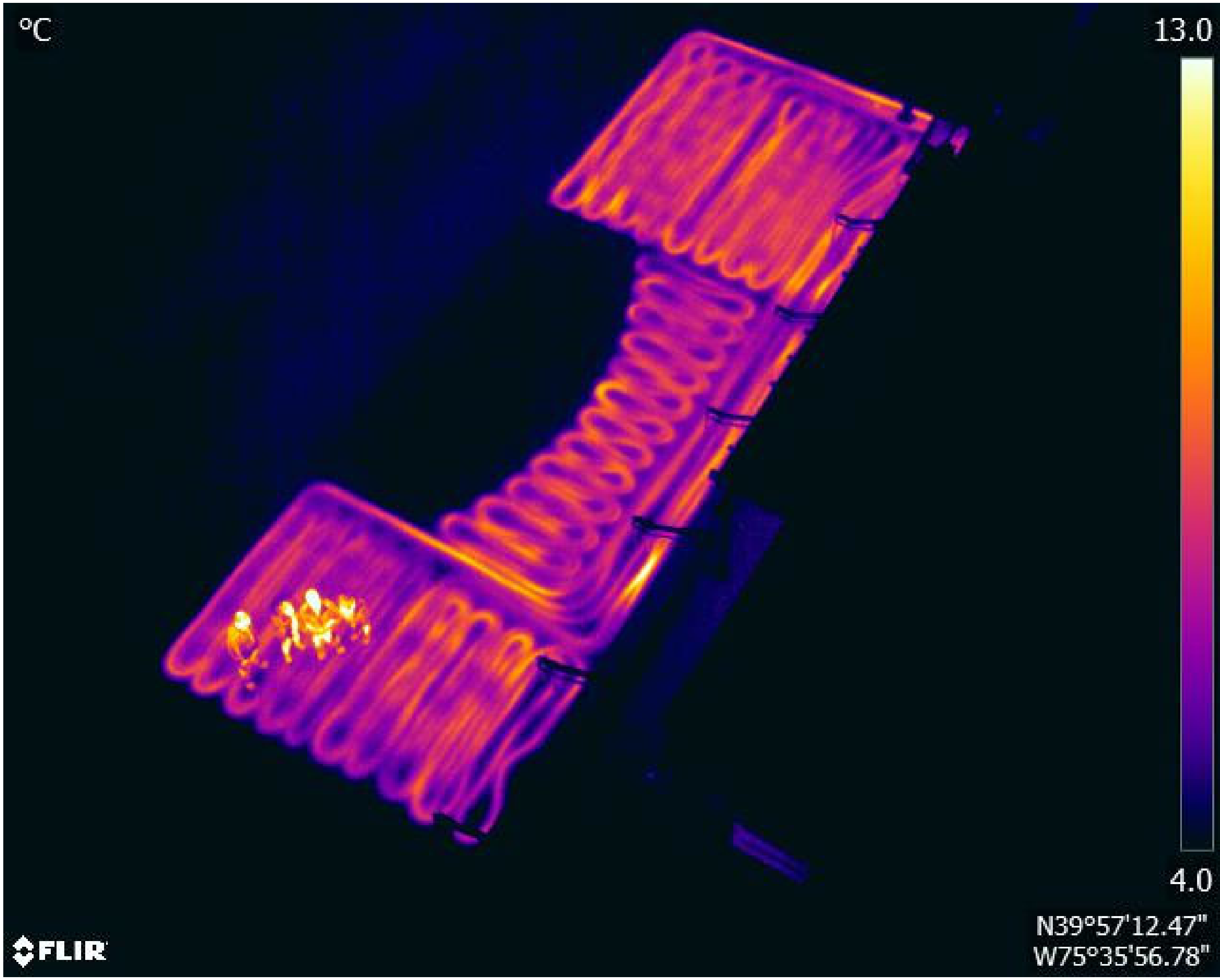
Residential spring hydrogeologic investigation



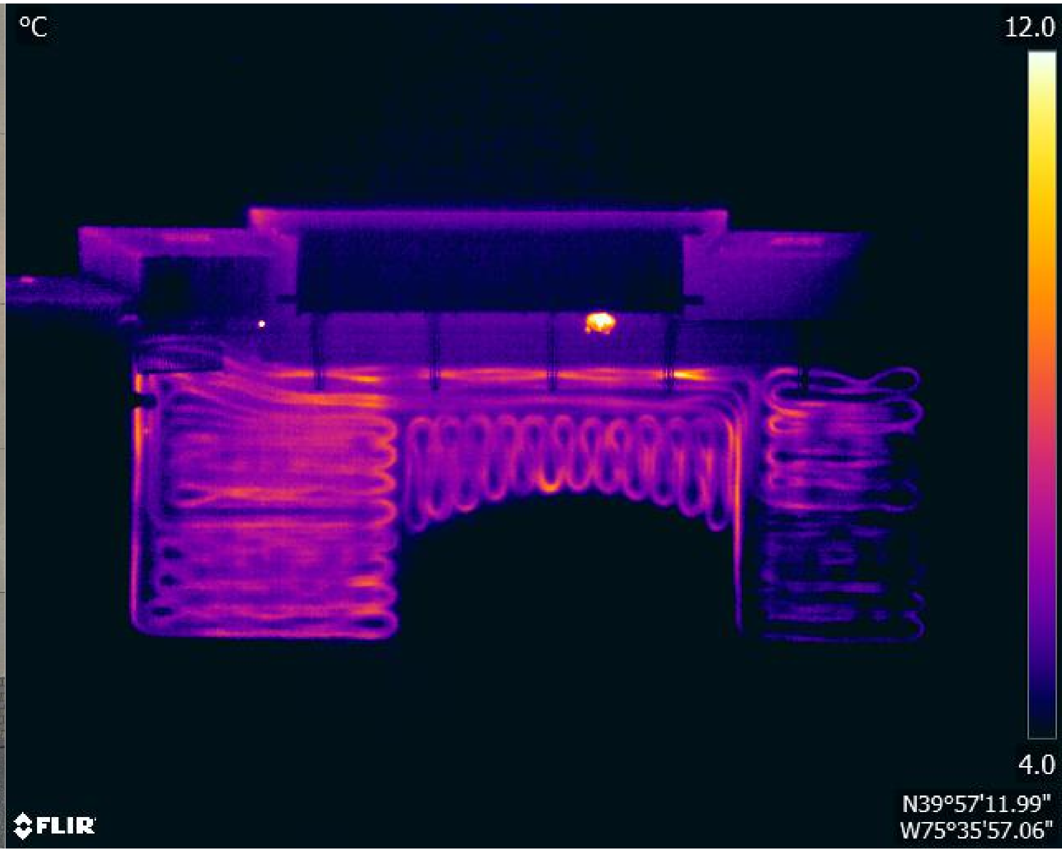
Orthomosaic of 40 images,
Zenmuse XT2 Thermal Camera

Thermal Drone Experiment Feb 2020

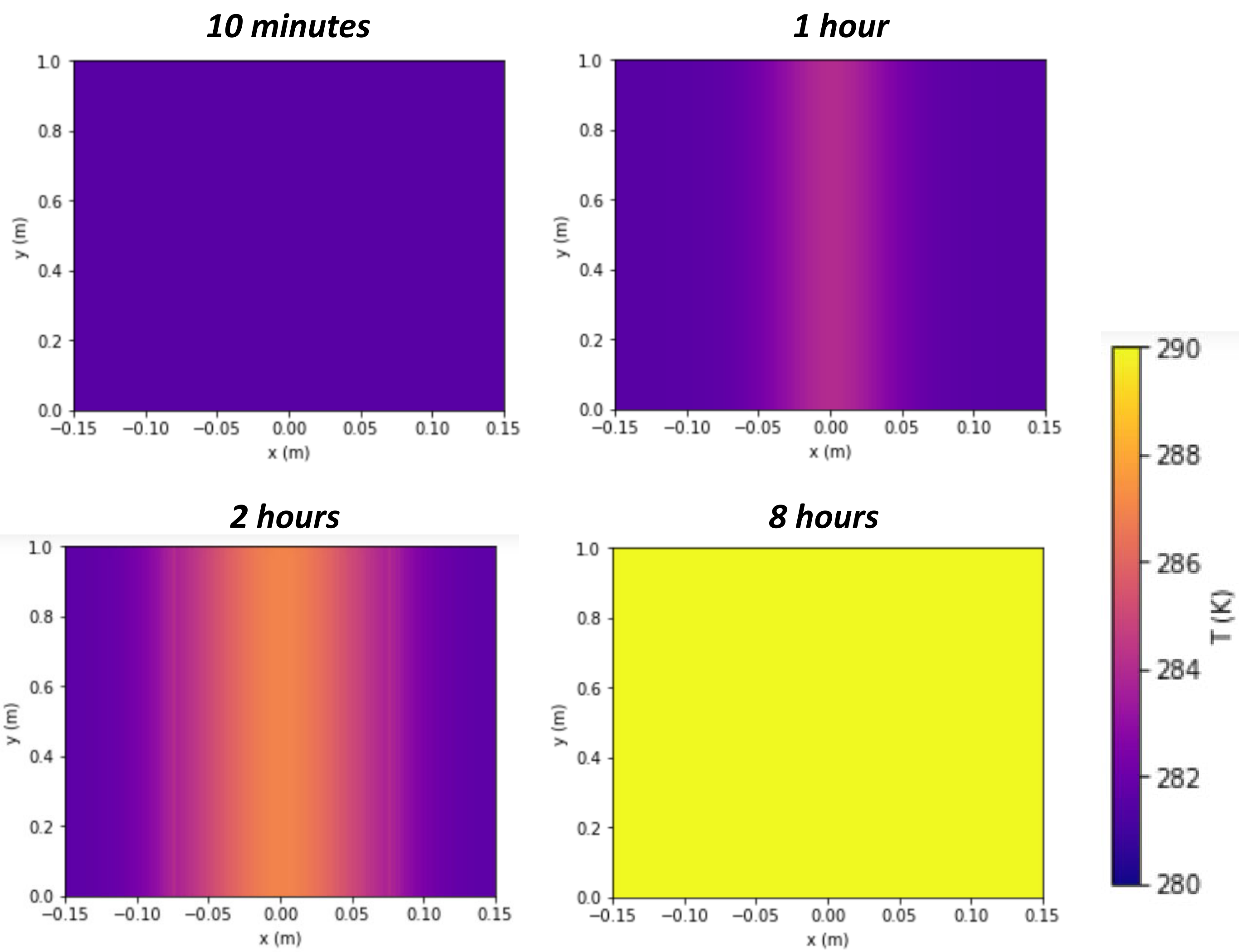
Abby Keebler



Aerial EO and Thermal IR Imagery



Heated Sidewalk Simulations



$Q = \lambda A i$ *Fourier's Law*

$$\frac{\partial^2 T}{\partial x^2} = \frac{S_{VC}}{\lambda}\frac{\partial T}{\partial t}$$

$$T = \frac{Q}{4\pi T} W(u)$$

T = temperature
Q = heat flux rate
k = thermal conductivity

$$W(u) = \int_u^\infty \frac{e^{-y}}{y}\, dy$$

$$u = \frac{r^2 S_{VC}}{4kt}$$

r = radius (distance)
S_{VC} = volumetric heat capacity
t = time

Thermal UAS
Heated Sidewalk Pilot Project

According to our modeling:

- *1 TJ of heat energy/year to balance current geothermal system*
- *Operating heated surface 8 hrs/freezing day*
- *3,100 m^2 area*
- *3,100 m (2 miles) heated sidewalk*
- *Or the Lawrence parking lot*
- *Cost \$650,000 at \$215/m^2*

Goodman Construction, 2019

Conclusions

- Sustainable operation of geothermal systems require thermal balancing
- Deicing salt causes significant short-term and possibly chronic impact to streams
- Heated surfaces have the potential to both balance the geothermal system and protect aquatic organisms

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